Evaluation and Improvement of the Design Process within Henrob Ltd

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Abstract

Henrob is a large engineering organisation that specialises in the manufacture of joining technology for use in the automotive sector. The company has recently been acquired by the large industrial organisation Atlas Copco Group. As part of this acquisition, Henrob has been tasked with the implementation of lean manufacturing methods to firstly evaluate and then improve product development lead time within the UK design team.

The role of lean management methods within manufacturing organisations is very well understood. However, the role of lean within new product development is less well so. If Henrob could employ the well-known benefits of lean thinking like waste reduction and information flow and be aware of the complex and intangible nature of the product development stage, leading to reduced product lead times and improved process efficiency, then this could represent a substantial competitive advantage over its competitors.

This research is a quantitative cross-sectional study using the experimental research method to test a series of hypotheses. The research initially used process mapping to uncover inefficiencies within the design process that were subsequently addressed by further research. The research experiments were based around the use of new CAD templates designed to reduce errors and improve work flow through the design office. The research was partially successful with regards to lead time reduction and increasing design output. However, improved information flow and higher quality, more cost-effective designs were considered more important outcomes of the research.

Declaration

This work is original and has not been submitted previously for any academic purpose. All secondary sources are acknowledged.

Signed:

Date:

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Chapter 1

1. Introduction

1.1. Background to the Research

Henrob is a large engineering organisation that specialises in the design and manufacture of self-piercing riveting equipment used primarily in joining operations in automotive assembly lines. Henrob has recently been acquired by the Swedish engineering company, Atlas Copco Group. As part of the acquisition, Henrob has been set a new company-wide objective known simply as the forty-ten-eight objective. This means that Henrob will push towards designing forty products per week whilst at the same time delivering those products in a ten-week lead time and supply spare parts in an eight-week lead time. Value stream mapping was used to identify areas of waste across the organisation. The design process was identified as a substantial source of non-value adding activities. Improvements here could lead to significant gains in both design output and design lead time. A reduction in design lead time would lead to a direct reduction in overall product lead time. For Henrob to meet the objective, design output must increase significantly. This will be achieved by increasing the number of design personnel but more importantly, will also require the design process to become much more efficient.

Henrob uses computer aided design (CAD) in a two-stage process to design products. Stage one involves the creation and development of a three-dimensional computer model of the product. Stage two adds additional parts and fasteners and prepares the three-dimensional model for two-dimensional drafting. This stage includes the production of final product specification drawings. These drawings are then used by many other departments that are involved in product build. The research will evaluate both the current stage one modelling design process and the current stage two drafting design process. The research will also evaluate new alternative modelling and drafting techniques with the aim of improving design output and design and product lead times in order for Henrob to achieve the forty-ten-eight objective outlined above.

1.2. Research Hypotheses, Aims and Objectives

As the research is experimental in nature, it was based around three research hypotheses. Hypothesis one is related to objective two and it states that 'the use of new CAD tools will lead to a significant decrease in design modelling lead time'. Hypothesis two is related to objective three and it states that 'the use of new CAD tools will lead to a significant decrease in design drafting lead time'. Hypothesis three links design and drafting lead times to design output. It states that 'a decrease in design modelling and drafting lead time will lead to an increase in design output'.

The use of new CAD tools did lead to a reduction in design lead time for both stage one and stage two design processes. This also led to an increase in design output. Design output was further improved by introducing lean methods throughout the design process.

The research also has a number of general research aims.

1.2.1. Research Aims

The research aims can be summarised as follows:

- To evaluate the current design process using lean manufacturing techniques.
- To improve information flow through the design office.
- To increase overall design output.
- To reduce design lead times that will lead to reduced overall product lead time.
- To investigate emerging CAD technology developments.

Four specific research objectives have been developed in order for the research aims to be accomplished.

1.2.2. Research Objectives

1.2.2.1. Objective One

To assess the current design process and CAD technology used within the design office at Henrob. This objective will process map the current design process.

1.2.2.2. Objective Two

To measure the potential improvement in lead time in the stage one modelling design process by the use of new CAD tools. Lead time is directly linked to design output. Current output is 10 tools/week. New target is 20/week.

1.2.2.3. Objective Three

To measure the potential improvement in lead time in the stage two drafting design process by the use of new CAD tools. Lead time is directly linked to design output. Current output is 8 tools/week. New target is 16/week.

1.2.2.4. Objective Four

To draw conclusions and recommendations from objectives two and three and to investigate future CAD technology developments that may have a positive impact on the design process.

1.3. Justification for the Research

Recent value stream mapping activities have identified the design process as an area that could be continuously improved. As the product design process is one of the most labour and time intensive design activities within the organisation, any improvements here could lead to significant gains in lead time, design output and other benefits.

Henrob's competitors currently offer new product designs to their customers with a similar lead time. If Henrob could reduce its current product lead time to ten weeks, then this would represent a significant competitive advantage over its competitors. Simplifying or improving the flow of information through the design office also reduces design costs and improves product design and overall product quality.

Henrob could use the research to align different design processes across other Henrob companies into a single coherent global design process.

The research will assist the researcher in completing two of their yearly objectives set out in an annual appraisal which are related to objectives two and three. It will also assist the researcher in obtaining an MBA degree which was a requirement for career progression into their current role. The researcher holds a keen interest in current and emerging CAD technology and how these could be integrated into the current design process.

1.4. Methodology

The research was based around a series of experiments that have been designed to test the research hypotheses. The experiments used current CAD tools to measure design time. This was then compared to a planned intervention using new CAD tools. Post-test design times were then compared to pre-test design time measurements.

Although Henrob has many different design functions, due to limited resources and time, this research will be limited to tool design within the UK.

The research approach was deductive or theory testing using research hypotheses. Data was analysed quantitatively using Microsoft Excel to determine whether a relationship exists between the independent and dependent variables (Saunders, Lewis, & Thornhill, 2012).

Purposive non-probability typical case sampling was used to select ten typical case designs as the total new design population size is unknown.

Chapter two will justify the experimental method. Chapter three will describe the experimental methodology in detail.

1.5. Outline of the Chapters

1.5.1. Chapter Two

Chapter two will critically review the current literature on lean manufacturing techniques, CAD and its use in new product development and the proposed research methods. This should expose gaps in current thinking and specifically, knowledge gaps at Henrob that may be reduced or closed by this research.

1.5.2. Chapter Three

Chapter three will describe the research methodology. This chapter will include the research philosophy, approach and justification of the selected research method. Research standards including validity, reliability, generalisability, experimental procedures and the data collection method will also be described in this chapter.

1.5.3. Chapter Four

Chapter four will present the findings and assess them in relation to the research hypotheses. This chapter will begin by explaining the findings from process mapping for both stage one and stage two design. It will then present the findings for each experiment for objectives two and three. Finally, it will analyse the findings for both objectives using statistical methods to establish any variable relationships.

1.5.4. Chapter Five

Chapter five will discuss the interpretation of the findings. This chapter will critically evaluate the chosen experimental method and each research objective and how they relate to the research hypotheses. This will naturally lead to conclusions about the research hypotheses and whether they are true or false. Limitations of the research and opportunities for further research will then be discussed.

1.5.5. Chapter Six

Chapter six will present recommendations based on the conclusions from chapter five. This chapter will briefly discuss new and emerging technologies that could have additional positive benefits to the design process. Chapter six will also include an implementation plan in the form of a Gantt chart.

1.6. Definitions

1.6.1. Definition of CAD

Henrob uses three-dimensional solid modelling CAD software called Solid Edge. The term CAD refers to the Solid Edge software. The term CAD tool refers to specific individual tools contained within the software. These tools may be used by designers many times throughout the product design process.

1.6.2. Definition of Tool Assembly

Although Henrob has many product lines, this research will be based on Henrob's premier product known as a tool assembly. Tool assemblies or tools are the riveting machines that are attached to the end of robots on automotive assembly lines. It is these tool assemblies that rivet the vehicle body panels and chassis together.

1.7. Summary

To achieve the forty-ten-eight objective, Henrob must improve its internal management processes across all departments and align similar processes used within different Henrob companies. This research will evaluate the current design process with the overall aim of improving this process.

The research is based around a number of scientific experiments designed to test the research hypotheses. The findings for all objectives will then be presented and critically analysed in relation to the research hypotheses and the literature review. Recommendations will then be made.

This research will help Henrob reduce processing inefficiencies or waste within the design process and improve design output whilst at the same time reducing overall product lead time. This should help Henrob to maintain and improve its long term competitive advantage over its rivals.

Chapter 2

2. Literature Review

2.1. Introduction

The literature review will evaluate current thinking on lean manufacturing. It will review the literature on current CAD technology and how this technology could be used in a more innovative and efficient way. It will review emerging CAD technologies that may be used to further improve the design process in the near future. The aim of the review will be to establish strengths and weaknesses in current thinking. It will help to determine whether gaps in current knowledge exist and how this research could help to reduce or close the knowledge gaps.

2.2. Lean Manufacturing

Lean manufacturing is a management philosophy that aims to identify and eliminate non-value adding activities or waste (Black, 2008). Non-value adding activities are those that a customer would be unwilling to pay for (Womack & Jones, 2006). Carreira (2005) defines lean manufacturing as a philosophy based on five principles, they are definition of value from a customer perspective, map the value and non-value adding stream, establish a flow of products, information and knowledge, implement a downstream pull system driven by the customer and pursue perfection by eliminating all waste through continuous improvement.

2.2.1. Benchmarking

Benchmarking is the process of identifying best practices in an organisation and then comparing similar processes to those organisations to help increase performance (Kumar, Antony, & Dhakar, 2006). It assumes that other organisations will have similar processes and problems and may have redesigned some operations to be more effective (Anand & Kodali, 2008). There are many different types of benchmarking. Strategic benchmarking compares long term goals and product development with other organisations. Internal benchmarking compares similar processes within the same organisation, whereas external benchmarking compares similar processes with different organisations (Slack, Brandon-Jones, Johnston, & Betts, 2015). Atlas Copco implemented a combination of strategic and internal benchmarking to help determine the forty-ten-eight objective. Internal benchmarking was used to compare the number of tools designed per week between Henrob UK and Henrob Corp (USA division). Henrob Corp were involved with a recent project to design and deliver twenty tools per week into the Ford Motor Company. It was decided that Henrob UK should also work towards delivering twenty tools per week. This would apply to two independent projects running concurrently which lead to the forty tools per week target. Strategic benchmarking was used to ensure that both Henrob companies were working toward the same long term objective of reduced lead time. The ten-week lead time and eight week spares lead time came from a twenty-five percent reduction in current lead times.

2.2.2. Value Stream Mapping

Research by Khan, et al. (2011) reports that although lean manufacturing techniques have been successfully employed by manufacturing organisations for many years, there was limited application when applying these techniques to new product development (NPD) or product and process development (PPD). They argued that value stream mapping could be useful when used in a product development environment but many organisations failed to do so due to the lack of research and clarity of how to implement this lean tool. They also differentiated between product/customer value and process value. One example of process value is the capture and retention of knowledge. Knowledge could include data sheets, check lists, engineering standards, guide lines and digital CAD information. They argued that although lean techniques help in the elimination of waste, the establishment of a flow of information and knowledge being pulled from customer requirements is more important. Objective one will use process mapping and the input-transformation-output model to map the current state of the tool design process. This should expose barriers to knowledge flow and areas that are creating waste by the inefficient use of information. Currently specification information flows from business development into the design department. This data is then used to generate digital CAD data that can subsequently be used by engineering, manufacturing, purchasing and the design department. The mapping process should help to uncover other lean wastes including waiting, defect, over processing and skills based wastes.

2.2.3. Knowledge Based Flow

In 2006, Baines, Lightfoot, Williams, and Greenough state that there could be significant benefits to employing lean principles to knowledge based activities such as design, engineering and new product development. They say that lean methods are moving away from the elimination of waste and towards the creation of value and establishment of knowledge flow. In a manufacturing environment, the creation of value is achieved by the flow of products, whereas in product development, value is created by the flow of information. The design process can be considered as a flow of information. Lean methods reduce waste in the design process by increasing the quality of generated information and reducing the amount of time before information is used. Value is created in the design process by the creation of knowledge and information that accurately represents the customer's specification.

Research by Letens, Farris and Van Aken (2011) also emphasised the fact that there is much less understanding of lean product development than there is of lean manufacturing. In a manufacturing environment, it is much simpler to employ lean tools to reduce waste in relation to real products and visible materials than it is to apply the same tools to the more complex and intangible environment of design.

2.2.4. Visual Management

In 2012, research by Lindlöf, Söderberg and Persson (2012) focused on the transfer of knowledge in product development environments. They also confirmed the lack of research in lean product development. They argued that organisations could benefit from the use of lean methods when applied to the transfer, use and reuse of existing knowledge. The design team within Henrob is familiar with these problems. It is currently difficult to quickly determine the status of the many design tasks flowing through the department. Often design information is difficult to find and retrieve which leads to knowledge loss and duplication of effort as old designs are reworked, a form of defect waste. Lindlöf, Söderberg and Persson (2012) argue that the use of visual management tools like Kanban and Kaizen boards could help improve the transfer of knowledge.

2.2.5. Knowledge Capture using Product Data Management (PDM)

Henrob is currently considering the implementation of a product data management (PDM) system (la Fontaine, Könst, & Hoogeboom, 2009). This type of database ensures much more control over the management of knowledge and engineering CAD data by collecting, storing and sharing data from one central point across the many engineering functional groups. PDM also simplifies the work flow by eliminating data loss and duplication of effort and reduces the amount of design rework. Some disadvantages of PDM are the initial cost and amount of preliminary work involved in installation, configuration and maintenance of the database.

2.2.6. Limitations of Lean

In 2005, Cooper and Edgett stated that using lean methods to reduce product development time can improve innovation by making more time available to develop a wider variety of products. They warn that when lean methods are over used, they can impede the development process by spending too much time on waste management.

Nayab (2011) reports that the constant focus on continuous improvement can produce high levels of stress and have a detrimental effect on employee motivation. Lean methods can lead to organisations becoming less flexible as processes are so well defined that it makes it more difficult to respond to unexpected events. This could also impact innovation and creativity. The key to a successful introduction of lean techniques to product development is good planning, effective change management, strong leadership and accepting lean product development as a change in culture rather than a change in methods.

2.3. Computer Aided Design in the Design Process

Computer aided design is a software tool that is used by Henrob to produce product concepts, visualisation of designs, product specification drawings and documentation. CAD has been used across a range of industries for many years and the advantages of using it are widely known and well documented (Kuang-Hua, 2016). CAD helps to reduce design lead times by automating many of the manual hand drafting methods. It does this by generating and storing large libraries of standard part models and drawings that can be reused in many different designs.

In 2012, Simmons, Phelps and Maguire state that the use of CAD systems can improve design times by introducing standard components and drawings that can be reused. It reduces drafting time, increases drafting accuracy and improves the flow of information by simplifying the creation, retrieval and modification of CAD models and drafts.

2.3.1. Knowledge Capture using Computer Aided Design (CAD)

In 2006, research by Tan and Vonderembse reports that the use of CAD in product development can help in reducing design lead times and costs, improve product quality and reduce development and manufacturing costs. They state that CAD is an important tool when used to facilitate the sharing of information and knowledge across both business and engineering functional groups. This also relates to objective one when considering the flow of CAD information across other areas of the organisation and how PDM may improve this (See section 2.2.5).

2.3.2. CAD and Product Development Life Cycle

Research by Vishwas, Vinyas and Puneeth (2016) reports that the use of CAD is very important in reducing product development lead times. A traditional approach to design would be to design, build, evaluate then manufacture. A more modern approach is to design and validate much earlier in the development process by designing, building and testing simultaneously, a concept known as simultaneous or concurrent engineering which is part of the lean product development philosophy. Objective one will expose wastes in the current design process, objective two will improve design modelling times. This will enable design validation to be completed much earlier in the development process and will contribute to improved design output.

2.3.3. The Research Method using CAD Templates

Objectives two and three will make use of predefined CAD templates to reduce design and drafting lead times. Templates are CAD models or drawings that contain a collection of predefined standard parts or drawing views and manufacturing information. Research by Tiwari, Jain and Tandon (2014) suggests that the use of CAD templates can reduce lead times considerably by automating some of the initial design stages. Using templates allows the designer to reuse previous design knowledge and reduce the amount of duplicated effort.

2.3.4. Limitations of CAD

Although Simmons, Phelps, and Maguire (2012) have stressed the benefits of using CAD in new product development, there are some disadvantages. CAD is expensive to implement and maintain. It is a complex piece of software that requires expensive workstations and regular specialist training. The quality of information that it produces is only as good as its source. Models and drawings still require error checking and approval processes. However, CAD represents a huge improvement over the manual drafting method.

2.3.5. CAD and the Future

In 2009, Ray predicts that CAD will continue to become ever more powerful whilst at the same time becoming much easier and quicker to use. He states that product data management (PDM) will become an integral part of the CAD software which would save implementing expensive standalone PDM systems.

Hirz, Rossbacher and Gulanová (2017) also report that data management will become increasingly more important as CAD data flows across more departments, customers and suppliers. To assist in the flow of information, they predict that cloud based storage will become important. Hirz, Rossbacher, Gulanová (2017) and Friedlander (2009) both predict that the CAD user interface and model-drawing visualisation will also change. CAD systems will move towards implementing mixed and augmented virtual reality. Holographic animation of models becomes possible using Microsoft's HoloLens or Google Glass.

These advances in CAD technology are related to a new paradigm in manufacturing known as Industry 4.0. Shafiq, Sanin, Szczerbicki and Toro (2016) describe Industry 4.0 as a modern trend towards the implementation of smart, highly advanced computerised factories. Organisations are now becoming more connected through the web and the 'internet of things'. Manufacturing and design knowledge and data management are central to success. Industry 4.0 is a concept that Henrob is already investigating and experimenting with to further improve processes across the organisation.

2.4. Conceptual Model

Lean manufacturing is already well established in production environments and is increasingly being implemented at the product development stage. Objective one will use lean methods to map the current state of the design process and identify areas that are underperforming. Figure 1 shows a conceptual framework of the research.

The literature review revealed the importance of value creation by the establishment of knowledge capture and flow. Creating new models and drawings of new products using current CAD tools can lead to duplication of effort as previous designs are not reused, a form of knowledge loss. Current CAD tools also run the risk of introducing errors each time a new design is created and represents a significant bottleneck to information flow in the design process. Objectives two and three will use custom designed CAD templates that can be reused many times for different designs. The templates will only have to be checked for errors once beforehand and will help reduce the CAD bottleneck and design times by improving information reuse and flow through the design process.

The literature review also revealed some interesting insights for the future. Holographic visualisation of new products would be very useful for virtual tool design and build and part interference detection, a form of defect waste. The concept of Industry 4.0 is probably the most important new development. This concept emphasises the importance of increasing connectivity, simulation and data management. Manufacturing and design functions will be virtually simulated much earlier in the product life cycle, further compressing new product development lead times.

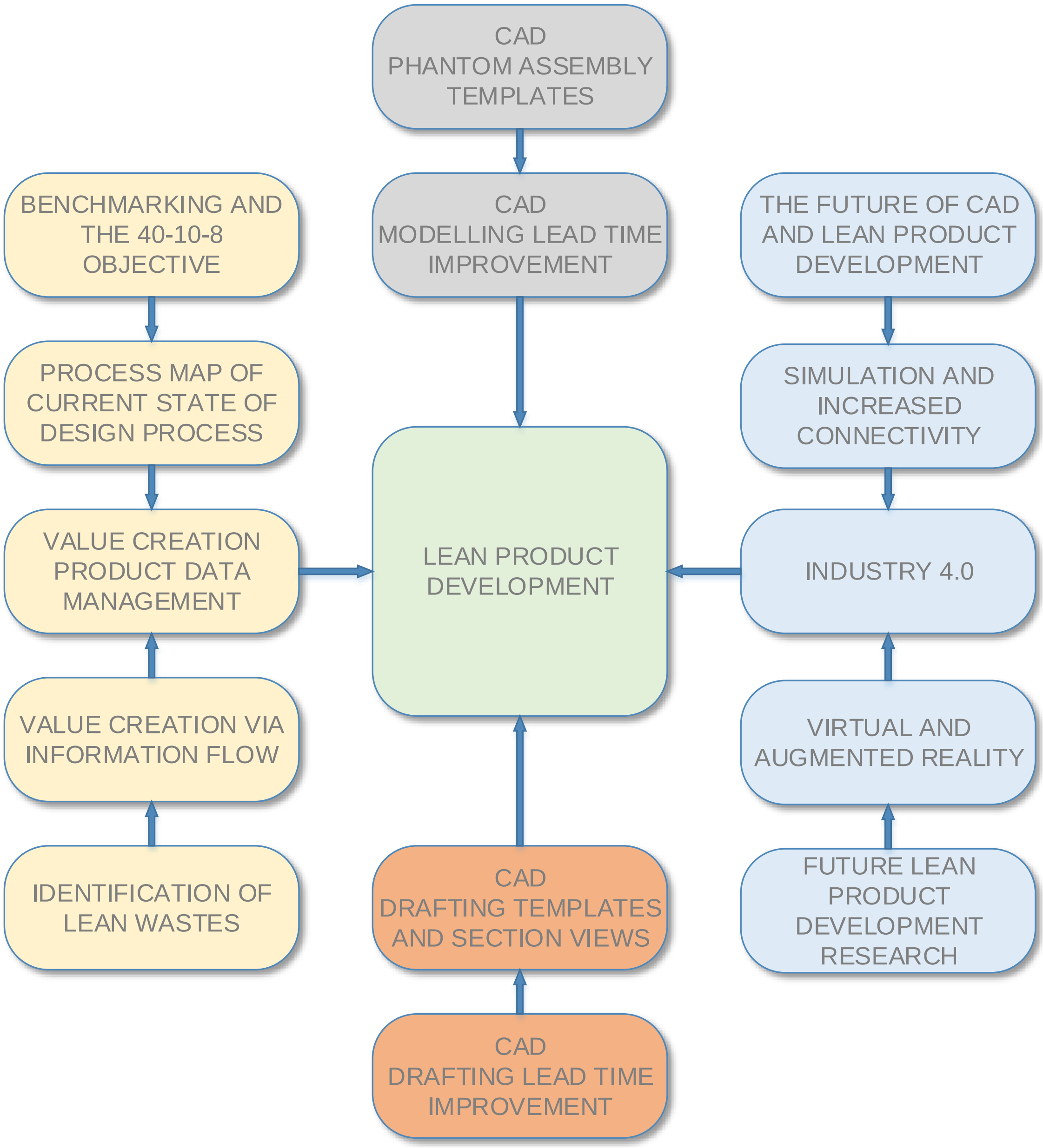

Figure 1 showing conceptual framework of the research

2.5. Summary

The literature review clearly identified a knowledge gap due to the lack of research when applying lean methods to new product development. It established the importance of waste reduction, knowledge capture and the creation of added value through efficient information flow through the design process. The literature review also identified a methodological gap. Many sources reported the generic benefits of implementing CAD and CAD templates to reduce design lead times. However, there were no examples of the specific CAD templates that will be implemented in objectives two and three. There also exists a knowledge gap within Henrob as this research will be original to the organisation.

The literature review also revealed the importance of new future technologies and in particular, the Industry 4.0 paradigm. This concept could revolutionise how organisations design and manufacture products in the near future.

This research will help to reduce the knowledge gaps outlined above and add to the existing body of knowledge on lean product development. To streamline the design process, Henrob must implement lean product development and utilise CAD tools and new technologies in a more efficient and innovative way.

Chapter 3

3. Research Methodology

3.1. Introduction

This chapter will begin by discussing the research philosophy and research approach. It will then discuss the selected and rejected methodologies in relation to the research hypotheses. The research design will then be described in detail, including a description of the variables, sampling, data collection and analysis and research standards. Experimental design, research instruments including CAD templates, procedures and the pilot study will then be discussed. Finally, limitations of the method and ethical issues will be considered.

3.1.1. Research Philosophy

The research philosophy relates to the nature of reality and knowledge, how knowledge is generated or developed and how it is analysed (Saunders, Lewis, & Thornhill, 2012). Ontology can be considered a study of the nature of reality and how the researcher views the world about them. The researcher is currently employed in a science based role and takes the position of a natural scientist. The researcher’s ontological viewpoint is that of an objective reality. This philosophical perspective views facts and truths that are value free and independent from an individual’s internal biases, feelings or personal interpretations.

Epistemology can be considered a study of the nature of knowledge, how it is generated and collected and whether it is acceptable to use in research. The researcher’s epistemological viewpoint is that of a positivist. As the research is based on a series of scientific experiments, the researcher places greater importance on observable and measurable data where there is no role for values or subjectivity.

3.1.2. Research Approach

The research was based on a deductive approach. This scientific approach uses a set of hypotheses, in this case, 'the use of new CAD tools will lead to a significant decrease in design modelling lead time', 'the use of new CAD tools will lead to a significant decrease in design drafting lead time' and 'a decrease in design lead time will lead to an increase in design output' which are then tested by measuring and comparing control and intervention variables. Quantitative data will be collected for analysis. The results from the data analysis were then used to determine whether a relationship existed between variables and whether the hypotheses can be accepted or rejected.

3.2. Methodological Considerations

3.2.1. Justification of the Research Method

Henrob has been set a company-wide objective known as forty-ten-eight. For Henrob to meet this objective, it must improve design times and design output. The research evaluated the current design process with the aim of improving overall efficiency of the process. The important variable that was measured throughout all of the experiments for both objectives was time. As time is a quantifiable numerical value, this type of data lends itself more to a quantitative statistical study (Fisher, 2007).

The experimental method was chosen as the most appropriate method for evaluating process efficiency by measuring a control time and comparing this to an intervention time. This method was also chosen due to the positive literature reviews in relation to the use of CAD templates. The literature review also identified the importance of knowledge capture and reuse. CAD templates can be considered a form of knowledge capture that can be reused many times.

The design process operates in a highly-controlled engineering environment and already works to high scientific standards. The researcher is also familiar with the implementation and use of these scientific standards which further justifies the use of the experimental method.

3.2.2. Rejected Research Methods

The survey method using questionnaires and structured interviews was initially considered as a research method but was rejected as this method tends to be associated with exploratory or descriptive research. The use of qualitative data was also rejected due to the nature of the variable being measured, in this case, time. Qualitative data tends to be more subjective and is often associated with an interpretive philosophy when conducting exploratory research.

3.3. Research Design

The research design is quantitative as the numerical variable being measured is time. Time was chosen as the dependent variable as this was deemed most appropriate in relation to the forty-ten-eight objective and the desired reduction in both design and overall product lead times.

The research was based around a series of experiments designed to test the hypotheses outlined in section 3.1.2. For objective two, stage one design, a new CAD tool known as a 'phantom assembly template' was used as the intervention. For objective three, stage two design, three new tools known as 'fastener system', 'pre-defined drawing template' and 'section views' were used as the intervention. Using current CAD tools provides a control variable to measure any improvements from.

This research is explanatory in nature, meaning that it seeks to explain the causal relationship between the independent and dependent variables and to test whether the hypotheses are true or false.

The research is a cross-sectional or a 'snap shot' study that took place over a period of twelve weeks. This is due to academic and work related time constraints but the results will still be valid for the foreseeable future.

3.3.1. Dependent, Independent and Control Variables

The dependent variable can be defined as a variable that may change in response to a change in another variable (Fisher, 2007). For objectives two and three, the dependent variable was defined as design time which was measured in minutes. This variable had a tolerance of plus/minus five percent. The independent variable is the variable that will be changed to measure what affect this could have on the dependent variable. For objective two, the independent variable was defined as the selection of a ‘phantom assembly template’. For objective three, the independent variable was defined as the selection of ‘fastener system’, ‘pre-defined drawing template’ and ‘section views’. To establish a baseline datum to measure potential changes from, a control variable was used. The control variable was defined as the use of ‘current CAD tools’.

3.3.2. Research Population and Sampling

Simple random probability sampling was used to select research participants to perform the experiments. The research participants are all qualified engineers with similar amounts of design experience. Initially one engineer was required to perform experiments for each objective but this was increased to four engineers as the experiments progressed and more resources became available. The research participants’ identities will remain anonymous and will be referred to as W, X, Y and Z throughout the research.

Purposive non-probability typical case sampling was used to select ten representative designs to perform experiments on. This sampling method was chosen because the sampling frame did not exist. The new design population size, by definition, remains unknown. This method selected typical cases carefully to ensure that a relatively small number of designs will produce valid results for a large range of possible designs (Denscombe, 2014).

This sampling method was initially used to select a small number of new CAD tools to use in the experiments that were perceived as having the greatest chance of success.

3.3.3. Data Generation, Collection and Analysis

Data was generated using a software timer that was installed on each research participant’s desktop computer. Data was collected for the dependent variable before and after the intervention took place. This data was collected and analysed using Microsoft Excel. Simple bar charts were then used to present pre-test and post-test design time measurements. A parametric paired t-test was used to determine whether the mean difference between the variables is statistically significant and whether to reject or not reject the null-hypotheses (Saunders, Lewis, & Thornhill, 2012). A paired t-test was selected to analyse the data as this method compares one set of pre-intervention observations with a corresponding set of paired post-intervention observations (Statistics Solutions, 2017).

3.3.4. Research Standards

The experiments have been designed to ensure that they could be easily and reliably replicated by another researcher. One characteristic of the experiments is that they are based on a within group design. This means that participants are involved with both control and intervention experiments. This design could lead to familiarity within the experimental process and a subsequent loss of validity. To help improve validity, a counterbalanced approach was adopted. This research design sequences experiments so that a participant would never work on a control experiment and its corresponding intervention experiment (Saunders, Lewis, & Thornhill, 2012). Due to a lack of resources and some unforeseen problems with the experiments (see chapter 5, section 5.2) it was not possible to use an ideal counter balanced design.

Internal validity is a measure of how well the experiments have performed and was established when a causal relationship between the variables was statistically proven. External validity relates to whether the findings from the experiments could be generalised to other parts of the organisation with a similar design function. The findings will be used help improve similar design processes but it may be more difficult to generalise externally as the research is specific to Henrob (Bryman & Bell, 2011).

3.4. Research Method and Procedures

3.4.1. Experiment Design

Control models for objective two were generated using current CAD tools. Intervention models were then created using new CAD tools. The dependent variable was measured for both experiments.

The control models from objective two were then used to generate control drawings for objective three using current CAD tools. Similarly, intervention models from objective two were used to generate intervention drawings for objective three using new CAD tools and the dependent variable was measured for both experiments. The experiments for each objective have been designed with a counterbalanced approach, see Figure 2 and Figure 3. This would have ensured that research participants did not become familiar with control and intervention experiments. As mentioned in the previous section, due to a lack of resources, the control and intervention for experiment ten within objective three were both performed by participant Z.

Although this approach was used for experiments within each objective, it was not required when moving from experiments in objective two to experiments in objective three. For example, the same research participant could work on a control model for objective two and then work on the corresponding control drawing for objective three. This was possible because the research between both objectives is deemed to be sufficiently different that familiarity between objectives was not a concern.

Ideal Counterbalanced Design for Stage One Design Objective Two				
Research Participant	W	X	Y	Z
Control Experiment	1,2,3	4,5,6	7,8	9,10
Invervention Experiment	4,5,6	7,8,9	10,1	2,3

Actual Counterbalanced Design for Stage One Design Objective Two				
Research Participant	W	X	Y	Z
Control Experiment	1-11	0	0	0
Invervention Experiment	0	1,2,3,4	5,6,7	8,9,10

Figure 2 showing ideal and actual counterbalanced design for objective two

Ideal Counterbalanced Design for Stage Two Design Objective Three				
Research Participant	W	X	Y	Z
Control Experiment	1,2,3	4,5,6	7,8	9,10
Invervention Experiment	4,5,6	7,8,9	10,1	2,3
Actual Counterbalanced Design for Stage Two Design Objective Three				
Research Participant	W	X	Y	Z
Control Experiment	1,2,7	0	0	3-6, 8-10
Invervention Experiment	0	1,2,3,4	5,6,7,8,9	10

Figure 3 showing ideal and actual counterbalanced design for objective three

3.4.2. Experiments using Phantom Assembly Templates

Henrob uses current CAD tools to build a three-dimensional model of the product, see Figure 4. This part of the design process requires an engineer to laboriously search, select and insert many individual parts into a new product model. Objective two simplified this process by introducing a new CAD tool known as a ‘phantom assembly’ template, see Figure 5 below. A ‘phantom assembly’ is a pre-defined collection of individual parts and sub-assemblies that has already been checked and saved as a template. A tool design is completed by adding several different phantom assemblies together into a final master assembly model. This has the effect of simplifying this part of the design process by reducing the number of steps it takes to build a final design model. It also increases product design quality by ensuring only the correct parts are used which are those contained within the phantom assembly.

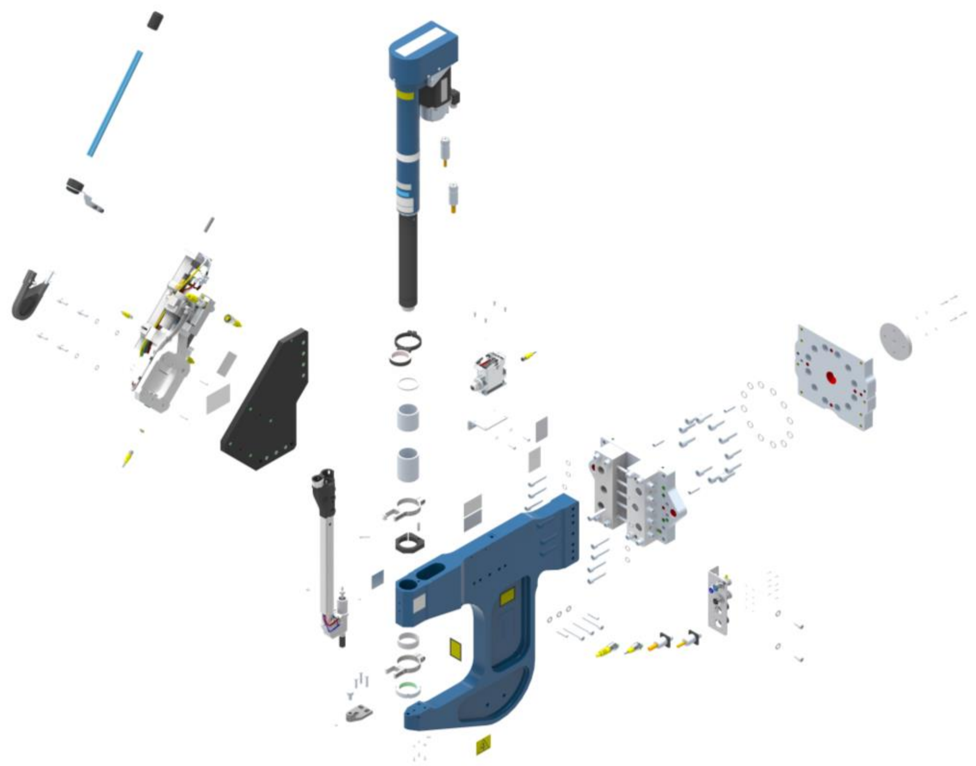

Figure 4 showing a tool design using current CAD tools

Figure 5 showing a tool design using phantom CAD tools

3.4.3. Experiments using Fastener System, Templates and Section Views

The tool design is completed by adding fasteners and a small number of final phantom assemblies and parts. Two-dimensional drawings are then generated from the three-dimensional model using current CAD templates, see Figure 6. It could be argued that the drafting stage of the design process is the most complex and labour intensive. Objective three simplified this stage by using a new CAD tool known as the 'fastener system'. This tool helps to automate and reduce the number of steps required to add fasteners to the final design. Two other tools were used at this stage, pre-drafted drawing templates and section views, see Figure 7. Simple section views replaced traditional time consuming exploded views.

Figure 6 showing current CAD drafting template

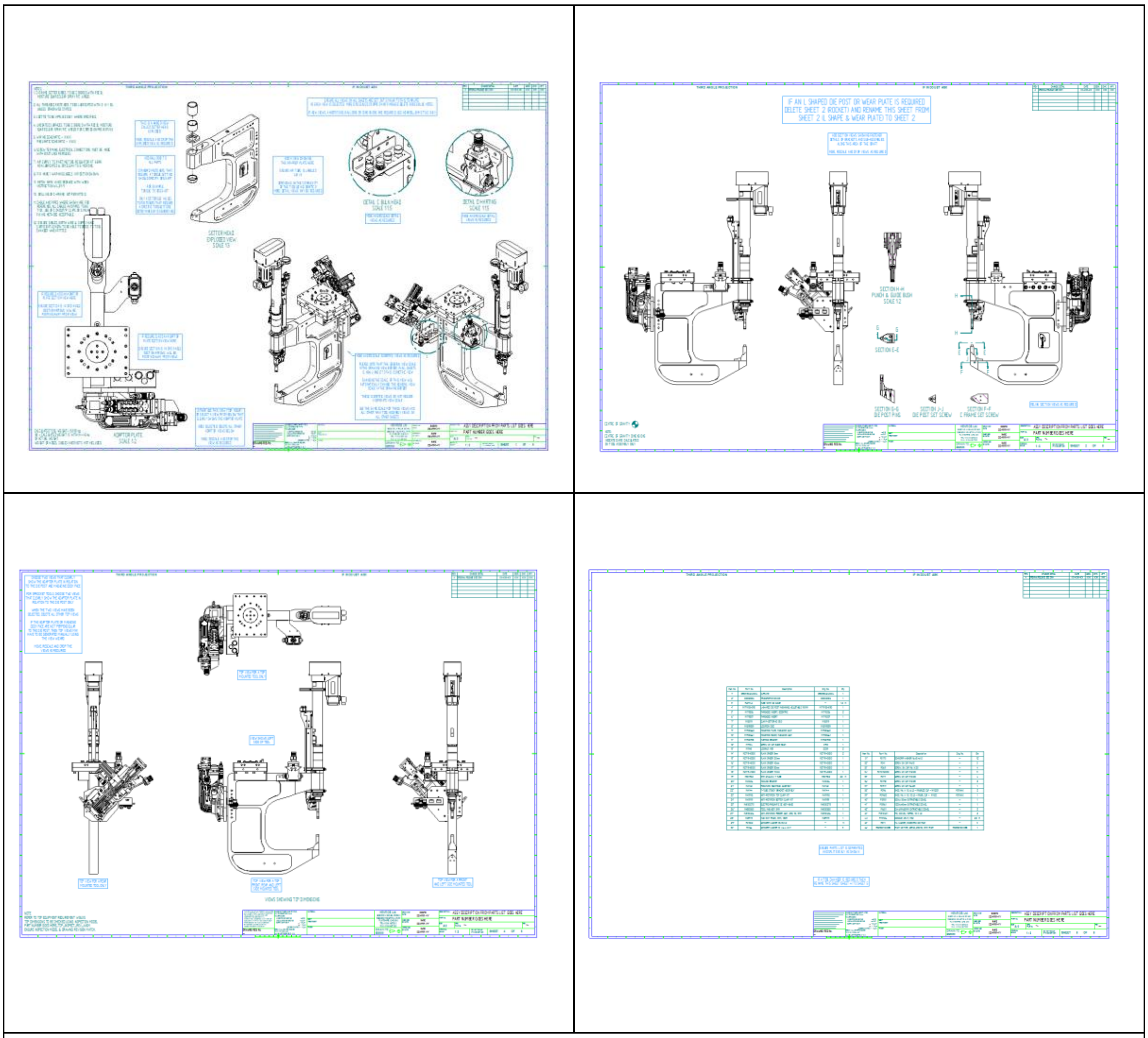

Figure 7 showing new CAD drafting template

3.4.4. Experiment Procedures

Four experimental procedures have been created to help research participants move through the experiments. The procedures, one control and one intervention for each objective briefly describes their purpose and where to find, retrieve and save experimental research data (see Appendix A and B for two examples of the four procedures). The procedures provided a fully detailed method for generating research data by performing the experiments. Importantly, they provided a detailed research scope of what each type of model and drawing should contain. This ensured that each type of model and drawing for each objective was the same which helped to maintain internal validity.

A data sheet specification was also provided for each sample type of tool design, equating to ten in total (see Appendix C). The data sheet provided initial design information, a small parts list and guidance on the tool design specification.

3.4.5. Pilot Study

A preliminary experimental pilot study was performed for both objectives and the initial results were positive. Internal validity seemed to be established as there was a clear causal relationship between the variables but this was not statistically proven. As there was a certain amount of overlap of objective two and three modelling, the pilot study was used to clearly define when objective two ended and objective three started. The pilot study was also used to generate the experimental procedures outlined above.

One important outcome from the pilot study was the feasibility of the 'fastener system' as a viable CAD tool. This tool was to be used on objective three to add fasteners to the model before drafting but it was realised that the fasteners would already be present in the models due to the use of 'phantom assemblies' from the previous objective. It was therefore decided to remove this CAD tool from the experiments.

3.4.6. Limitations of the Methodology

One limitation of the experimental method is that it requires experiments to be carried out in a highly-controlled environment. Although this helps with internal validity, it tends to reduce external validity. This limitation had less of an effect on the experiments as the design process already operates in a highly-controlled environment. Typical case samples were selected with care to ensure the findings could be generalised across other Henrob companies with similar design processes. Although it would be more difficult to generalise the findings externally, this is still possible as CAD templates are a common design process improvement method (Denscombe, 2014).

3.5. Ethical Considerations

Before the experiments could begin, some ethical considerations needed to be addressed. One issue was the measurement of the dependent variable and individual performance. Research participants were reassured that the measurement of design time was not a measure of their individual performance but a measurement of the design process performance. This also raised a secondary issue. As some participants were short term contractors, they expressed concern about the impact of the research on their current employment. This issue was settled when they were reassured that the aim of the research was not to improve the design process so that the number of employed contractors could be reduced but to reduce lead times and increase design output.

3.6. Summary

The research was based around a series of scientific experiments and used a deductive approach to test whether a set of hypotheses are true or false. This was achieved by collecting quantitative data for the dependent variable and testing statistically whether a causal relationship exists between the independent and dependent variables.

The experimental method was chosen primarily due to the variable being measured, which is time. This quantifiable value also relates back to the forty-ten-eight objective set by Atlas Copco. Simple random probability sampling was used to select research participants whereas purposive non-probability typical case sampling was used to select a small number of typical case designs that would produce the best results from a small sample.

The dependent variable was defined as design time. The independent variable was defined as the use of new CAD tools and the control variable was defined as the use of current CAD tools. Statistical paired t-test analysis using Microsoft Excel was used to establish whether the hypotheses can be accepted or rejected. The experiments used a selection of new CAD tools including ‘phantom assemblies’, ‘drawing template’ and ‘section views’. A preliminary pilot study was performed and initial results were positive.

Chapter 4

4. Analysis and Findings

4.1. Introduction

This chapter will present the findings from the research for analysis. Chapter five will then discuss the findings from chapter four in relation to the literature. Chapter four will begin by discussing the application of the research methodology. Objective one will provide an assessment of the current design process using process mapping. The findings and analysis from objectives two and three, stage one modelling design and stage two drafting design will then be explained.

4.2. Application of the Methodology

The experiments were completed within the design office at Henrob UK under the researcher's supervision. Intervention experiments for objective two were completed between 4th May and 12th May. Intervention experiments for objective three were completed between 22nd May and 19th June. Control experiments for objective two were completed between 26th June and 11th July. Control experiments for objective three were completed between 26th June and 28th July. Three research participants, X, Y and Z were selected at random to perform the intervention experiments. The participants were issued a participant information document and participant informed consent form. They were also issued tool data sheets, modelling and drafting guidelines and the relevant experimental procedure (see Appendices A, B and C). The experimental method normally starts with control experiments followed by intervention experiments. As the experiments were performed on a current live project, it was decided to complete the intervention experiments first which enabled valuable customer data to be generated quickly. Data analysis could only begin when all control experiments were completed. All intervention experiments were performed by the three research participants, X, Y and Z mentioned above. However, due to limited resources, only participant Z was involved with control experiments for objective three. A fourth participant, W, with no previous exposure to the research was recruited towards the conclusion of all experiments to ensure the deadline was met. Participant W completed all of the control experiments for objective two.

4.3. Process Mapping of Objective One

4.3.1. Overview of the Design Process

To begin evaluation of the design process, it was necessary to process map the current state at a strategic business level and at a more detailed design level. A business process can be defined as the transformation of one or more inputs into useful outputs. Inputs can include information, material and human resources. Outputs include information, products and services (Heizer, Render, & Munson, 2017). This value stream map would provide a visual map of the current design process. It would help to determine the information flow and where lean wastes and bottlenecks were occurring.

Figure 8 shows the design office at a strategic level and how it interacts with other departments throughout the product lifecycle.

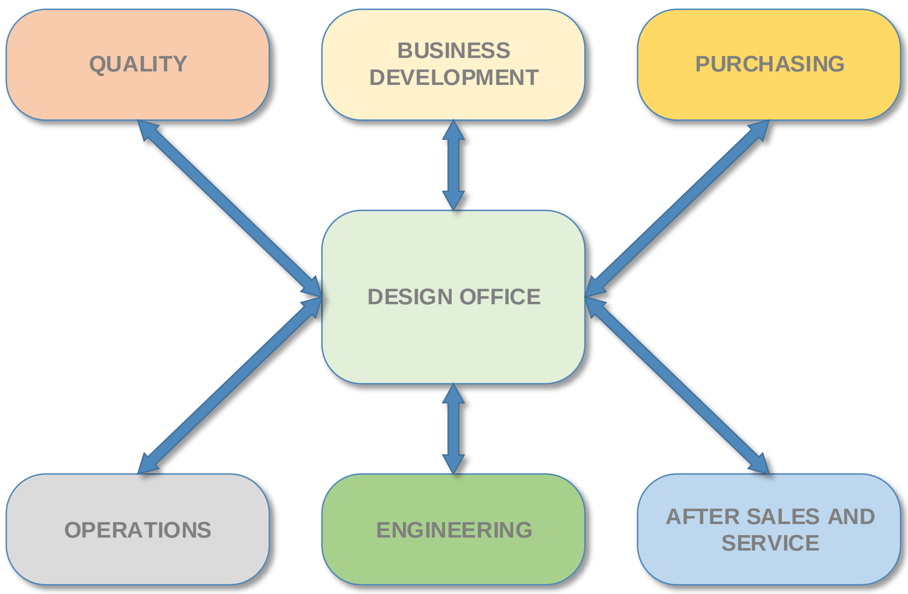

Figure 8 showing a strategic process map of the design office and other departments

At the beginning of the design process, the design office mainly interacts with business development, engineering and purchasing. As the product moves through design and into manufacture, there is more involvement with operations, quality and after sales and services.

Figure 9 shows a strategic map of the design process. New business enquires enter the organisation through business development. The design office is then tasked with producing new concepts and designs. Engineering and purchasing can both be involved at this stage for design validation and costing. Design validation ensures that the concept or new design will work.

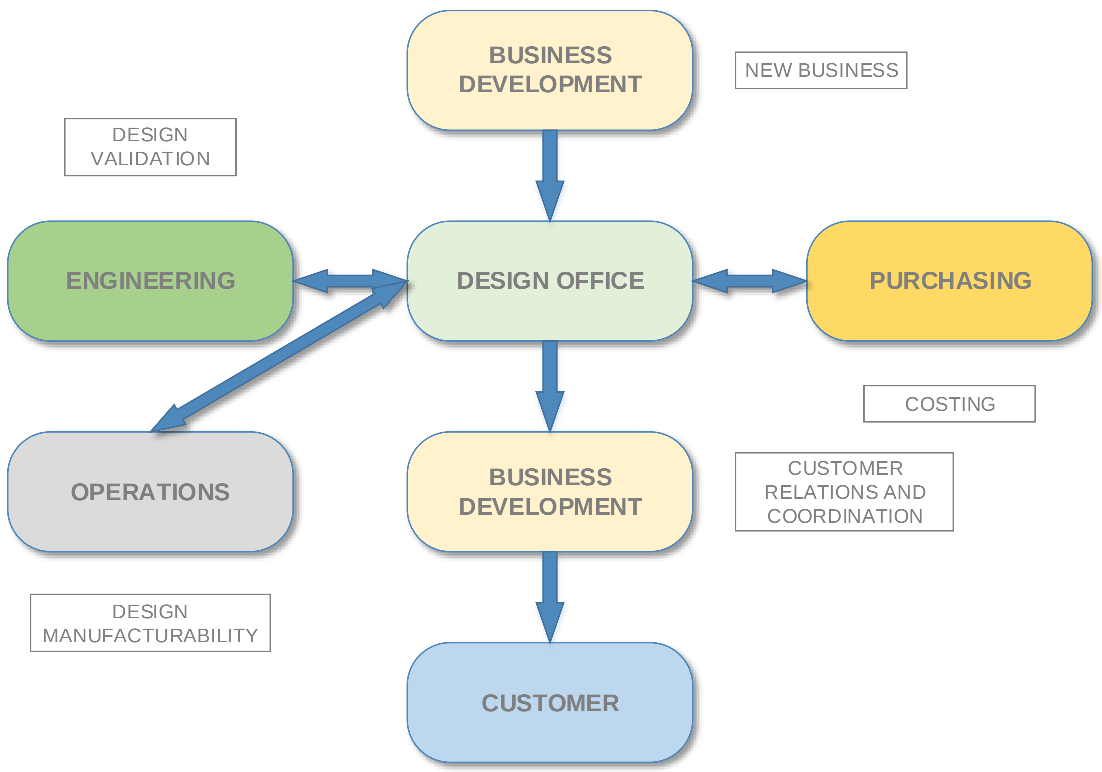

Figure 9 showing a strategic process map of the design process

Operations sometimes have limited involvement at this stage. Conceptual and design information then flows back through the design office to business development and finally to the customer. Although communications between departments is good, one area of concern is information flow between business development and design. This specifically involves the tool data specification sheet. This document contains important information on the type of product the customer has specified. It is complex, comprehensive, must be completed manually and is the source of many errors at the initial design stage.

4.3.2. Stage One Design Modelling Mapping

Stage one modelling involves the generation of a three-dimensional computer model of a customer product. To help determine how effective the stage one modelling process is, if there are any issues and where they were occurring, a highly-detailed map of the process was completed, see Figure 10. The mapping process uncovered several areas of concern.

As mentioned above, the initial transfer of information between business development and design using a data specification sheet can introduce many errors, a form of defect waste.

Computer aided design work then begins by selecting multiple individual components from a central parts library. This is also a source of defect waste as correct designs need to be completed using the correct parts. It is also a source of waiting waste as this stage of the design process is very inefficient, requiring a designer to select many different parts from many different library folders.

Another area of concern is when designs require engineering validation. Currently CAD models are created by the design office which are then sent to engineering for validation. Engineering then create another model for checking, a form of over processing waste. This model, once checked is then returned to the design office. This could introduce errors, leading to defect and transportation of information wastes. Engineering validation may take several attempts to ensure a robust working design and can introduce waiting wastes to other parts of the design process.

The final stage in stage one modelling design is checking the completed model against the data specification sheet. This is also a source of defect and waiting wastes.

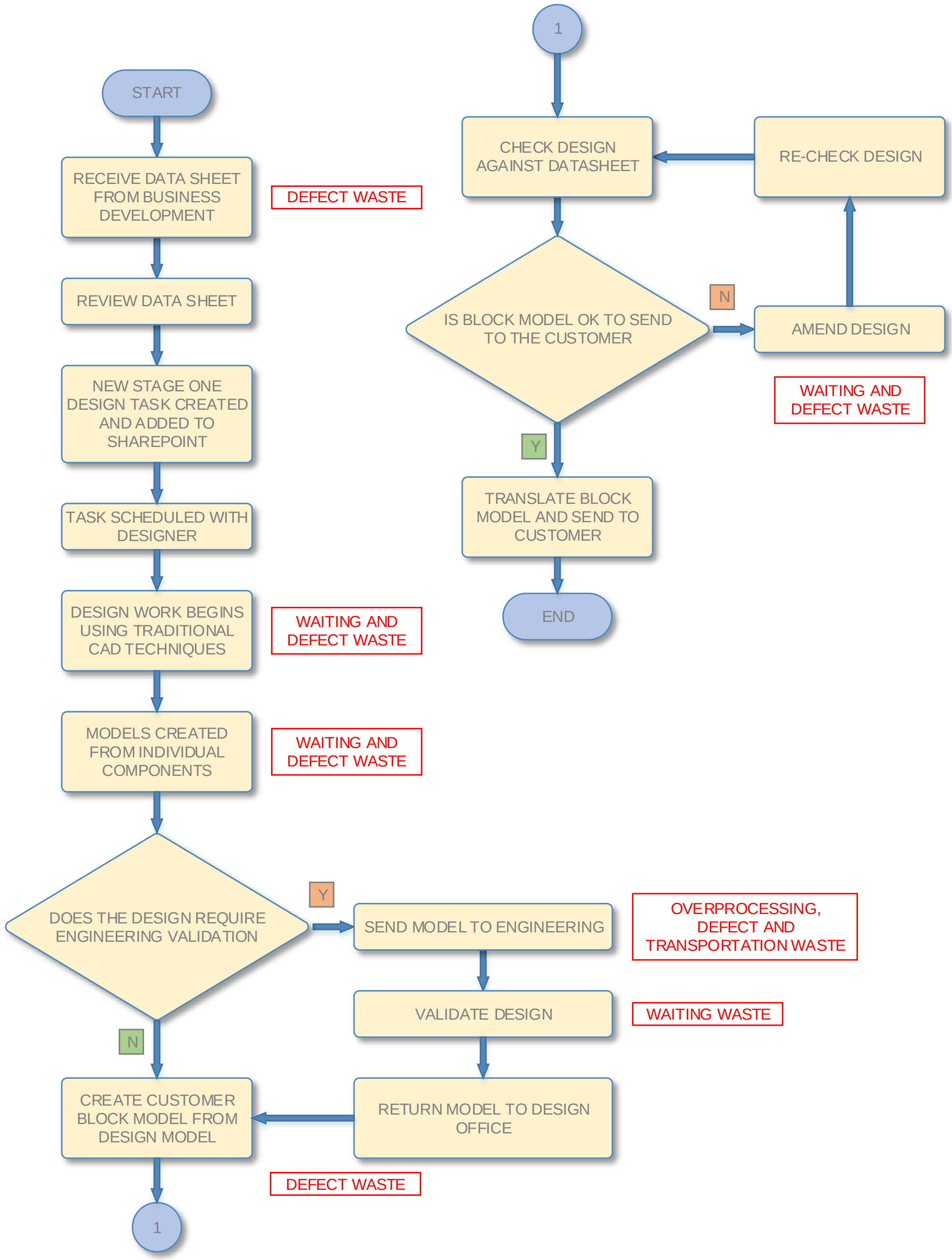

Figure 10 showing a detailed map of the current stage one design modelling process (Objective 2, modelling)

4.3.3. Stage Two Design Drafting Mapping

Stage two drafting involves completing the model in preparation for drafting. The model is completed by adding all fasteners and any additional assemblies and parts. This process was also mapped to determine if and where issues were occurring, see Figure 11. The mapping process uncovered several areas of concern.

Before drafting can begin, the completed model should be checked against the data specification sheet to ensure the correct parts have been used. This process is complex and time consuming, potentially leading to both defect and waiting wastes.

Drawings are then produced from clean blank templates. Producing fully annotated drawings with multiple plain and exploded views is very time consuming and easy to introduce many errors. This part of the drafting process could also be considered a talent waste as it requires a high level of knowledge and skill to produce finished drawings. Using lower skilled designers at this stage runs the risk of introducing more waiting and defect wastes.

The final stage in stage two drafting design is checking and approval. Checking is a source of defect and time waste as some errors still make it through this part of the process. Checked drawings are then sent to operations and engineering for approval. Two different levels of approval could be considered an over processing waste.

4.3.4. Summary of Objective One Process Mapping

Process mapping uncovered many areas of waste in both stage one and two design processes. The flow of information, the quality and the time taken to process the information were all areas that were uncovered by process mapping and were subsequently addressed by the research for each objective described in sections 4.4 and 4.5. This was achieved by simplifying the design process by the use of phantom assemblies and the introduction of pre-drafted drawing templates. Both methods introduced higher quality pre-checked information to both design processes that could be reused multiple times.

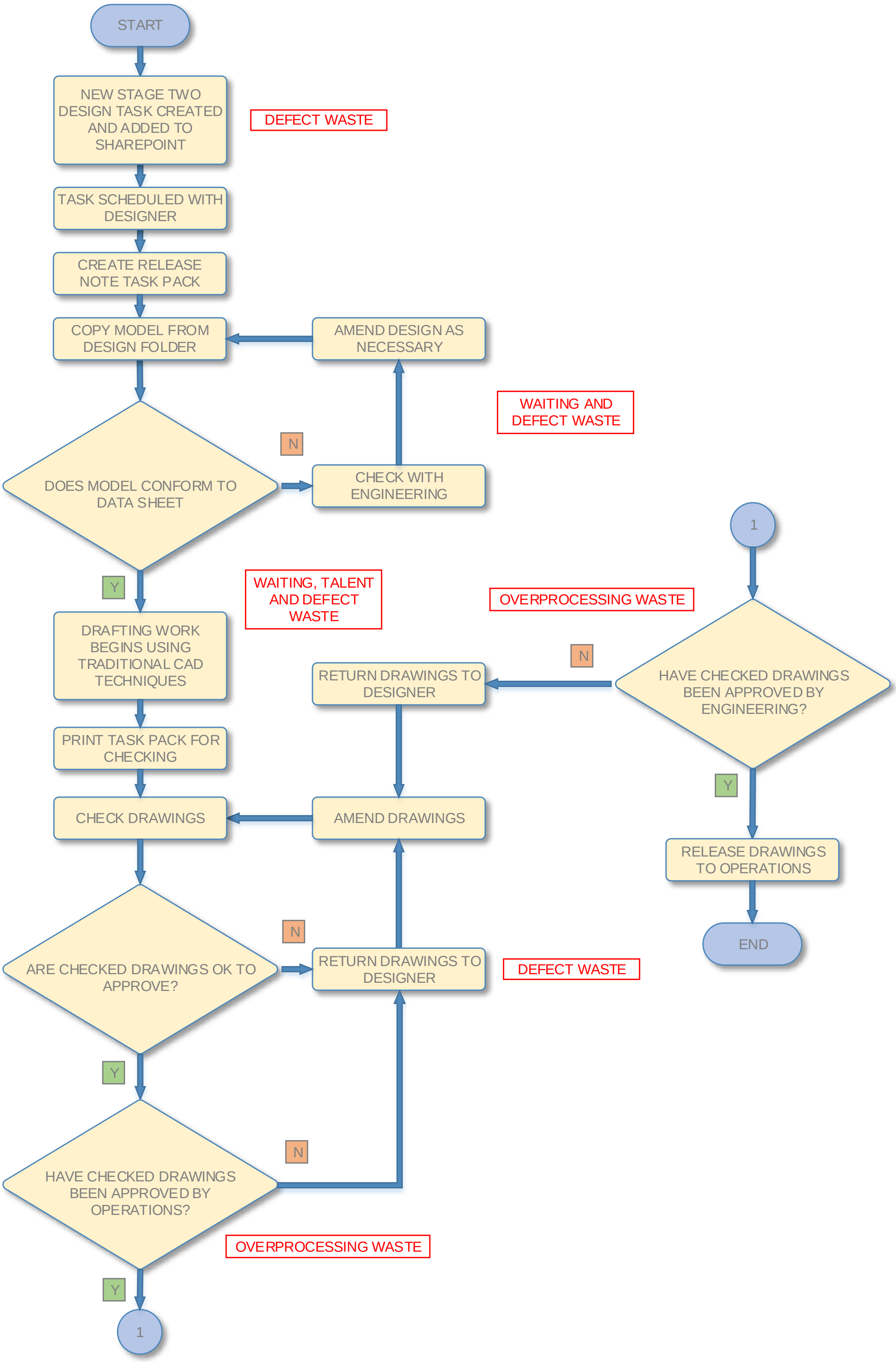

Figure 11 showing a detailed map of the current stage two design drafting process (Objective 3, drafting)

4.4. Findings and Analysis of Objective Two

Objective two measured the improvement in lead time in the stage one modelling design process by the use of new modelling CAD tools. A statistical significance test was used to determine whether to reject or not reject the null hypotheses. A null hypothesis would state that there would be no significant difference between the use of current and new CAD modelling tools. The experimental results and analysis will now be presented in the order that each participant completed them.

4.4.1. Experiment One

The control variable will be defined as design time using current CAD tools. This will provide a baseline for measuring any improvements from. The dependent variable is a variable that may change in response to changes to the independent variable and will be defined as design time.

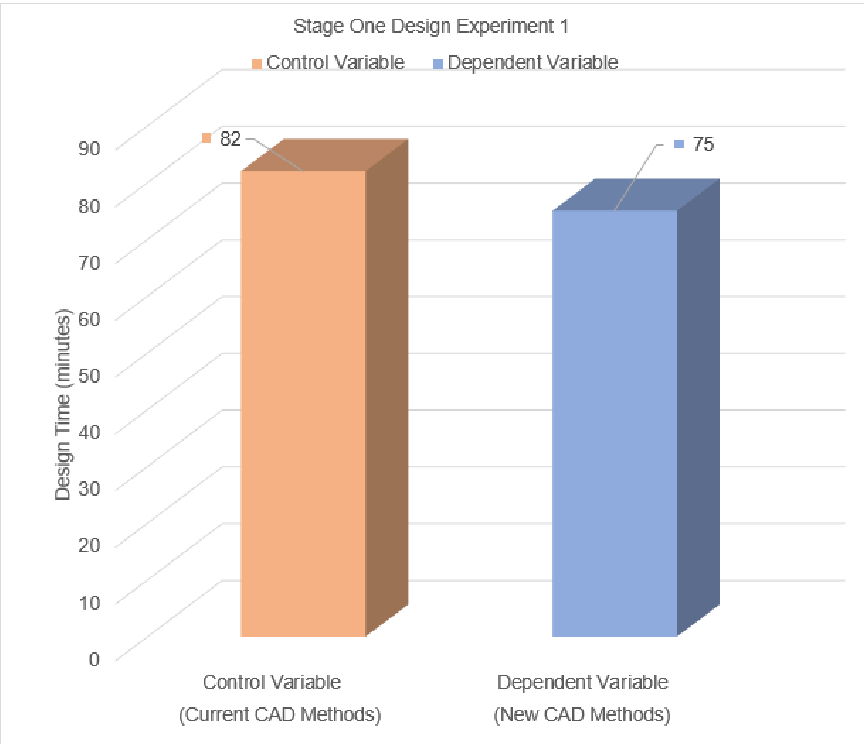

Figure 12 showing experiment 1 design times

(See Appendix D for source data)

The independent variable is the variable that will be changed in a planned intervention. For this objective, the independent variable will be defined as the use of a new ‘phantom assembly template’ CAD tool.

All control experiments for objective two were performed by research participant W. Experiment one was performed by research participant X. Figure 12 shows the results from experiment one. The control variable using current CAD methods for this experiment was measured at 82 minutes. The dependent variable using new CAD methods for this experiment was measured at 75 minutes. This represents a 9% improvement in design time.

4.4.2. Experiment Two

Experiment two was performed by research participant X. Figure 13 shows the results from experiment two. The control variable using current CAD methods for this experiment was measured at 78 minutes. The dependent variable using new CAD methods for this experiment was measured at 55 minutes. This represents a 29% improvement in design time.

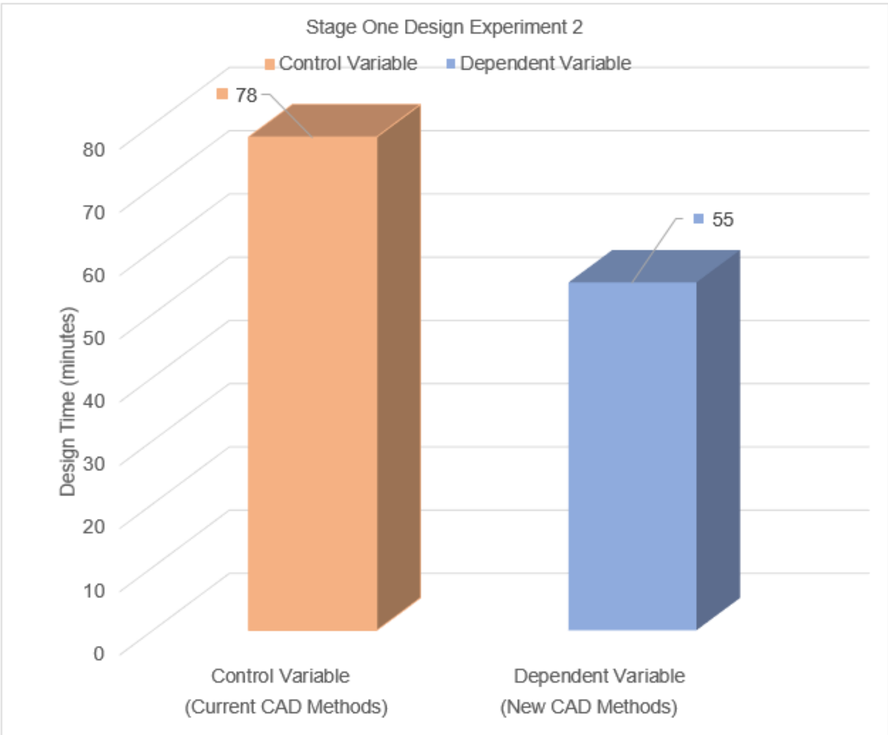

Figure 13 showing experiment 2 design times

(See Appendix D for source data)

4.4.3. Experiment Three

Experiment three was performed by research participant X. Figure 14 shows the results from experiment three. The control variable using current CAD methods for this experiment was measured at 108 minutes. The dependent variable using new CAD methods for this experiment was measured at 63 minutes. This represents a 42% improvement in design time.

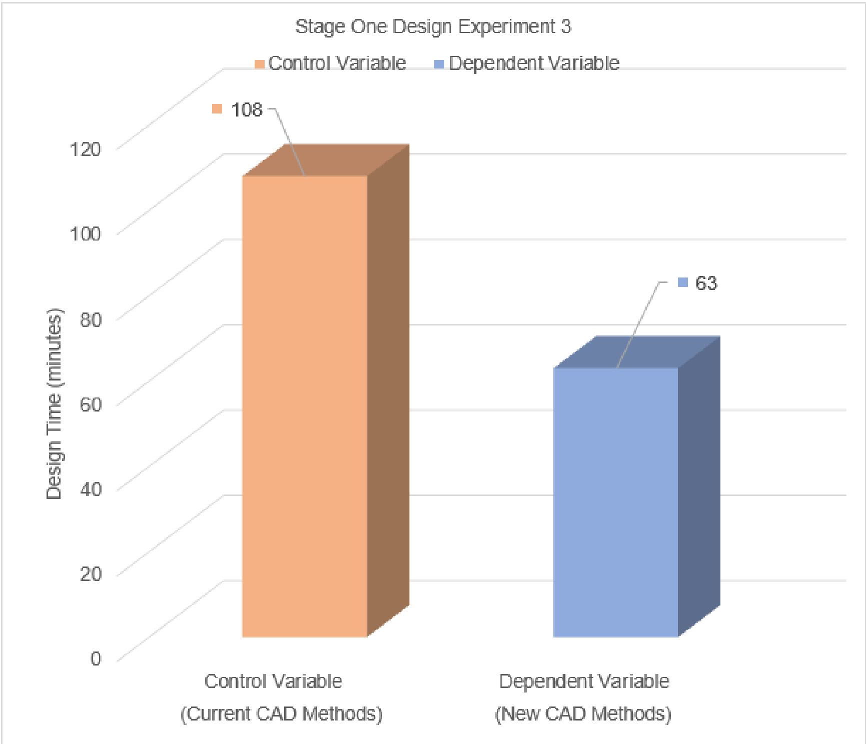

Figure 14 showing experiment 3 design times

(See Appendix D for source data)

4.4.4. Experiment Four

Experiment four was performed by research participant X. Figure 15 shows the results from experiment four. The control variable using current CAD methods for this experiment was measured at 77 minutes. The dependent variable using new CAD methods for this experiment was measured at 55 minutes. This represents a 29% improvement in design time.

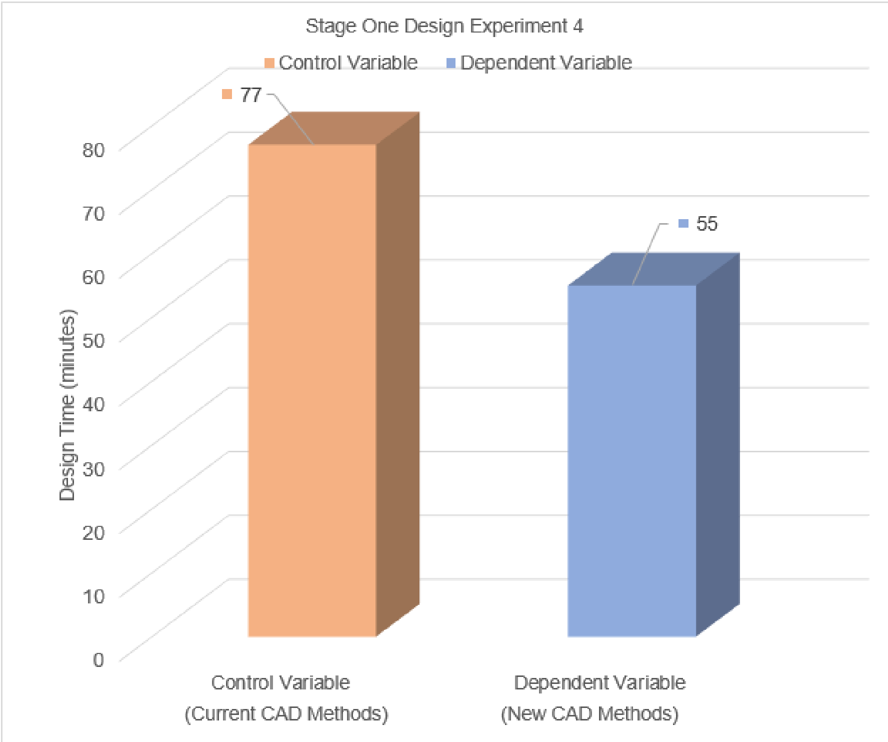

Figure 15 showing experiment 4 design times

(See Appendix D for source data)

4.4.5. Summary of Participant X Experiments

The four experiments of participant X showed an improvement in design time. See Figure 16.

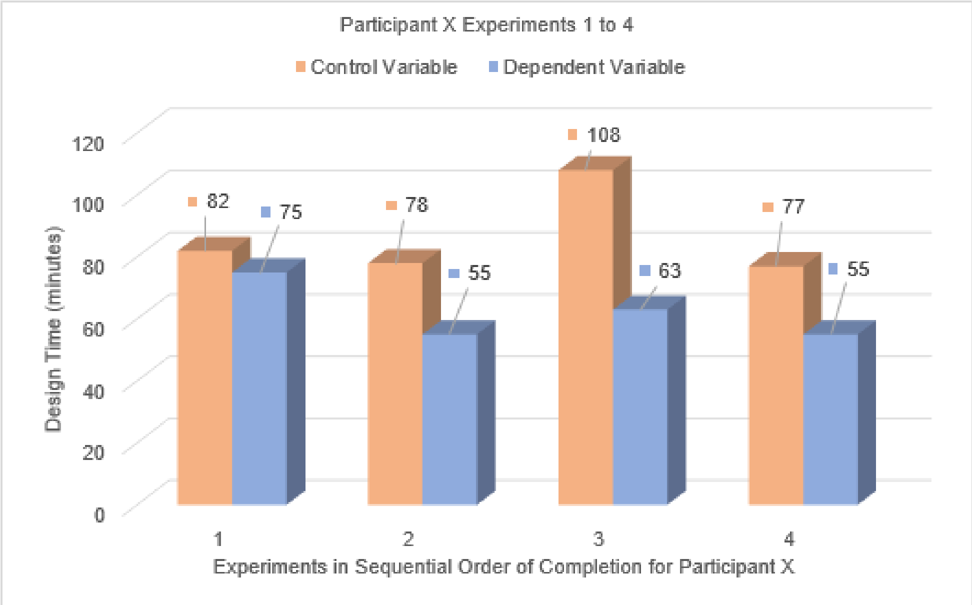

Figure 16 showing a summary of participant X design times

(See Appendix D for source data)

An average of all four experiment design times represented a 27% improvement when compared to the average control variable time.

4.4.6. Experiment Five

Experiment five was performed by research participant Y. Figure 17 shows the results from experiment five. The control variable using current CAD methods for this experiment was measured at 110 minutes. The dependent variable using new CAD methods for this experiment was measured at 105 minutes. This represents a 5% improvement in design time.

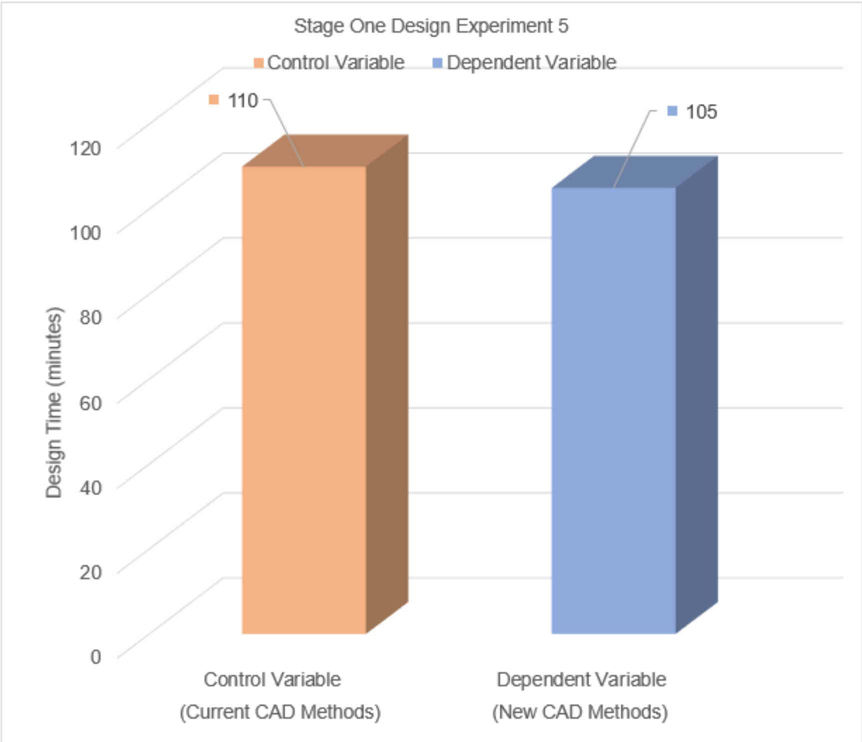

Figure 17 showing experiment 5 design times

(See Appendix D for source data)

4.4.7. Experiment Six

Experiment six was performed by research participant Y. Figure 18 shows the results from experiment six. The control variable using current CAD methods for this experiment was measured at 140 minutes. The dependent variable using new CAD methods for this experiment was measured at 45 minutes. This represents a 68% improvement in design time.

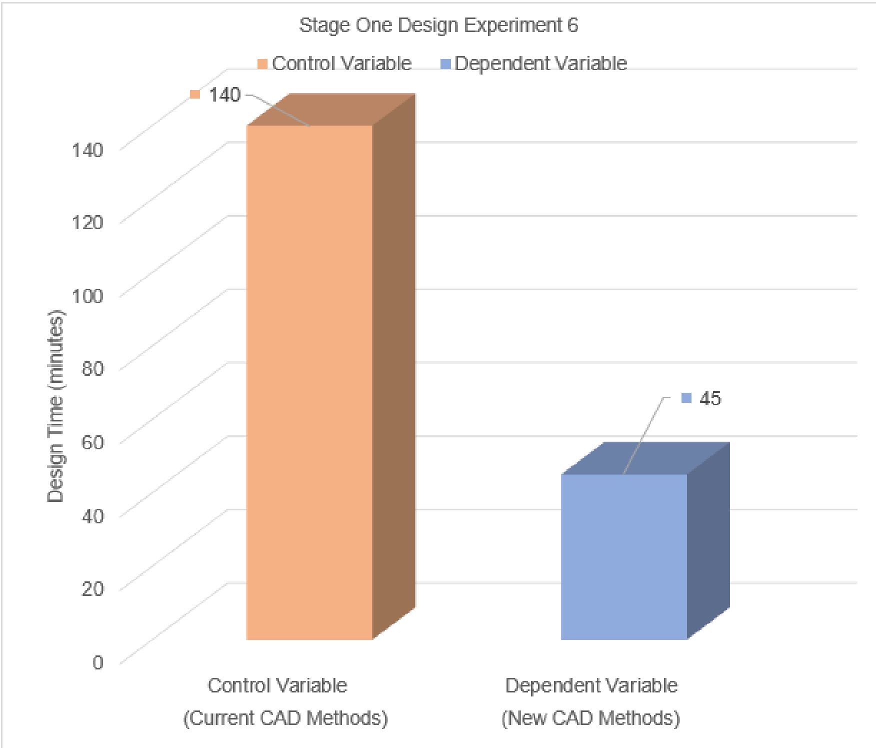

Figure 18 showing experiment 6 design times

(See Appendix D for source data)

4.4.8. Experiment Seven

Experiment seven was performed by research participant Y. Figure 19 shows the results from experiment seven. The control variable using current CAD methods for this experiment was measured at 75 minutes. The dependent variable using new CAD methods for this experiment was measured at 51 minutes. This represents a 32% improvement in design time.

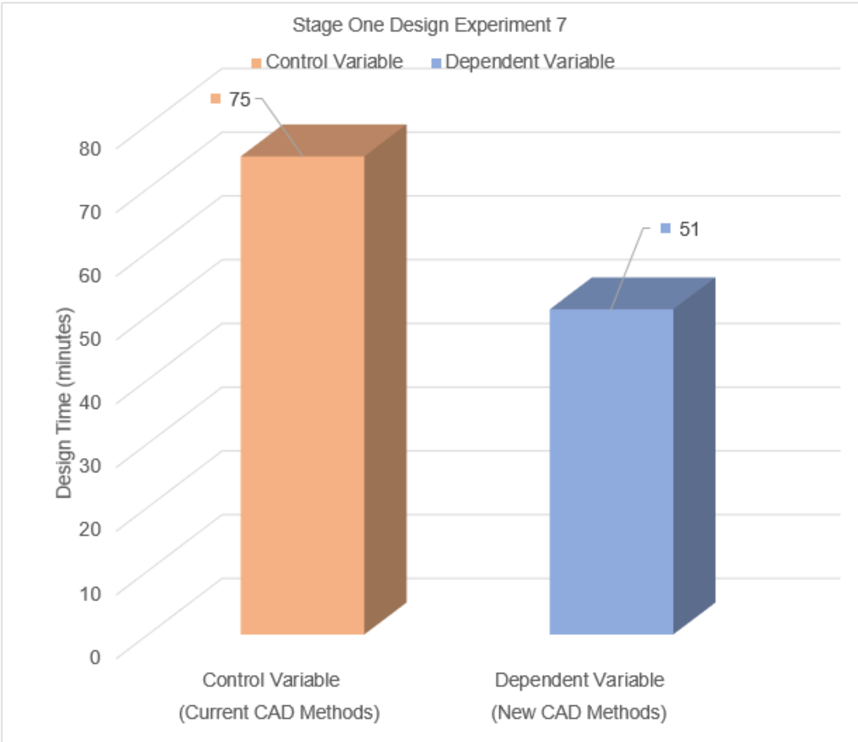

Figure 19 showing experiment 7 design times

(See Appendix D for source data)

4.4.9. Summary of Participant Y Experiments

The three experiments of participant Y showed an improvement in design time. See Figure 20.

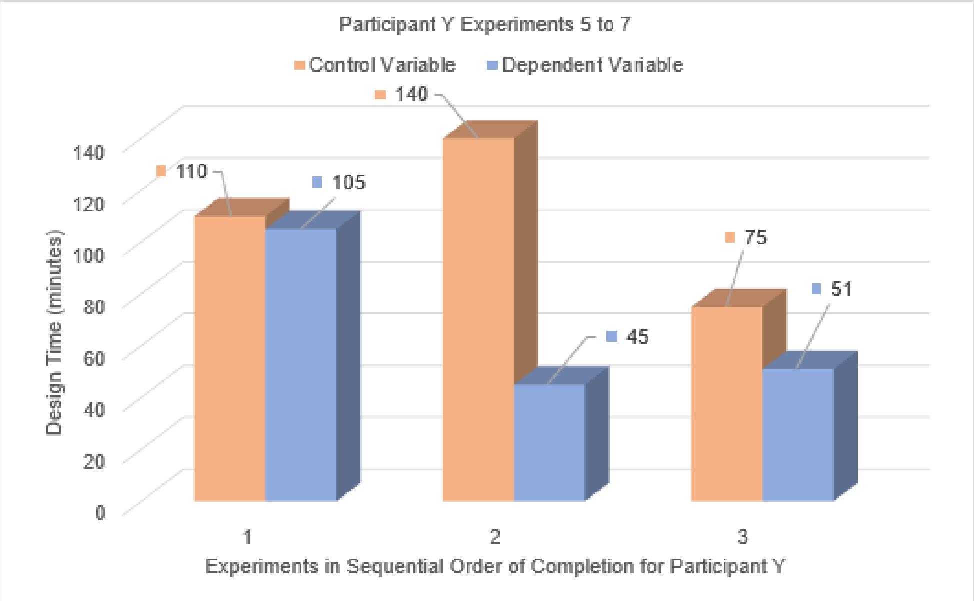

Figure 20 showing a summary of participant Y design times

(See Appendix D for source data)

An average of all three experiment design times represented a 35% improvement when compared to the average control variable time.

4.4.10. Experiment Eight

Experiment eight was performed by research participant Z. Figure 21 shows the results from experiment eight. The control variable using current CAD methods for this experiment was measured at 136 minutes. The dependent variable using new CAD methods for this experiment was measured at 71 minutes. This represents a 48% improvement in design time.

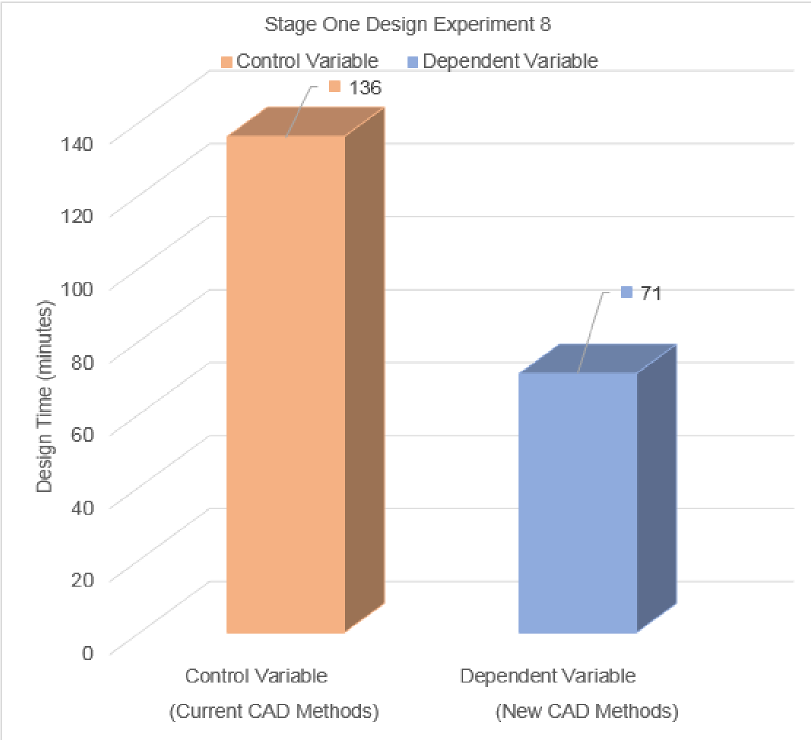

Figure 21 showing experiment 8 design times

(See Appendix D for source data)

4.4.11. Experiment Nine

Experiment nine was performed by research participant Z. Figure 22 shows the results from experiment nine. The control variable using current CAD methods for this experiment was measured at 160 minutes. The dependent variable using new CAD methods for this experiment was measured at 62 minutes. This represents a 62% improvement in design time.

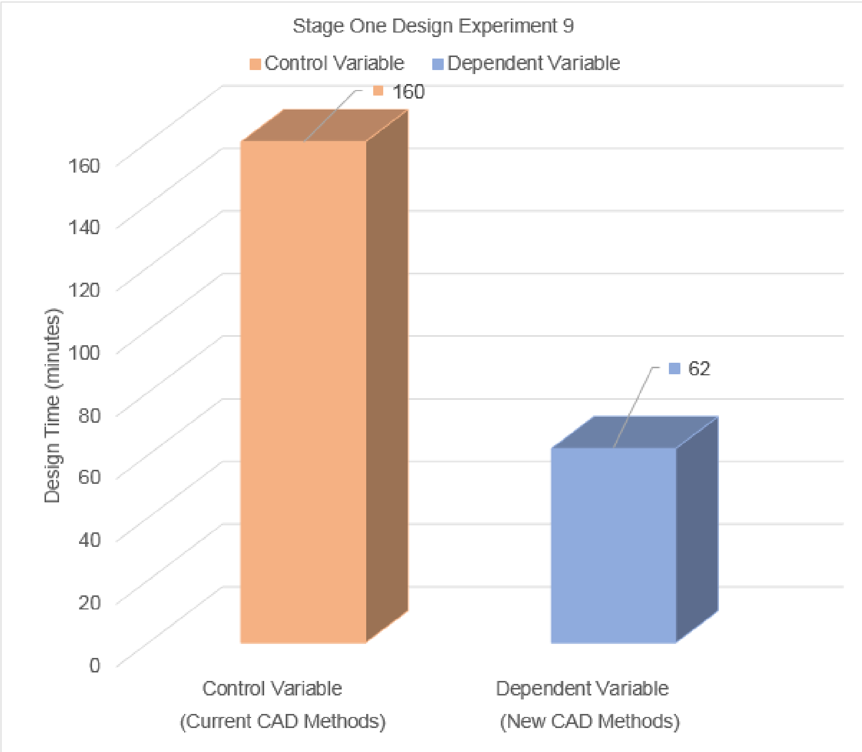

Figure 22 showing experiment 9 design times

(See Appendix D for source data)

4.4.12. Experiment Ten

Experiment ten was performed by research participant Z. Figure 23 shows the results from experiment ten. The control variable using current CAD methods for this experiment was measured at 120 minutes. The dependent variable using new CAD methods for this experiment was measured at 46 minutes. This represents a 62% improvement in design time.

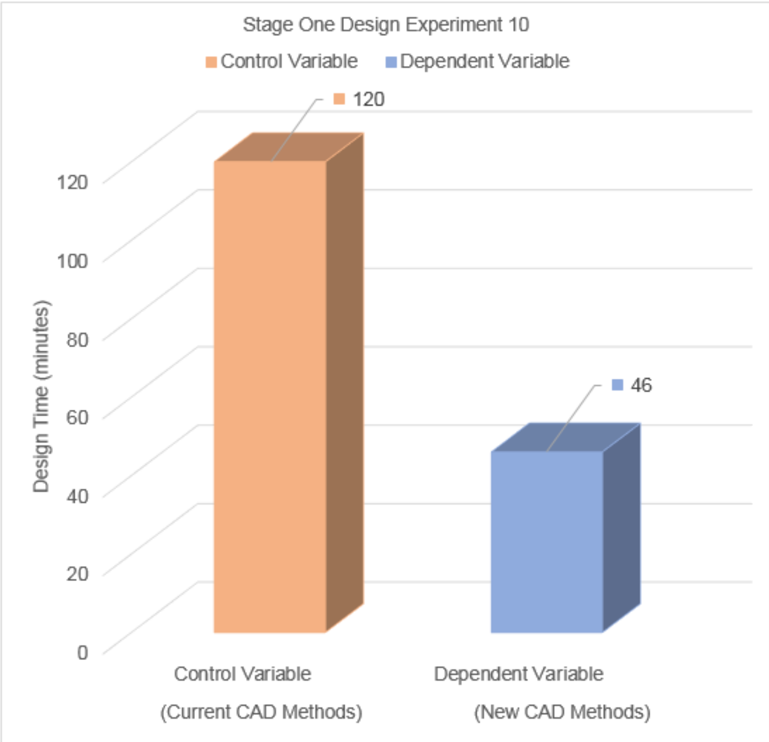

Figure 23 showing experiment 10 design times

(See Appendix D for source data)

4.4.13. Summary of Participant Z Experiments

The three experiments of participant Z showed an improvement in design time. See Figure 24.

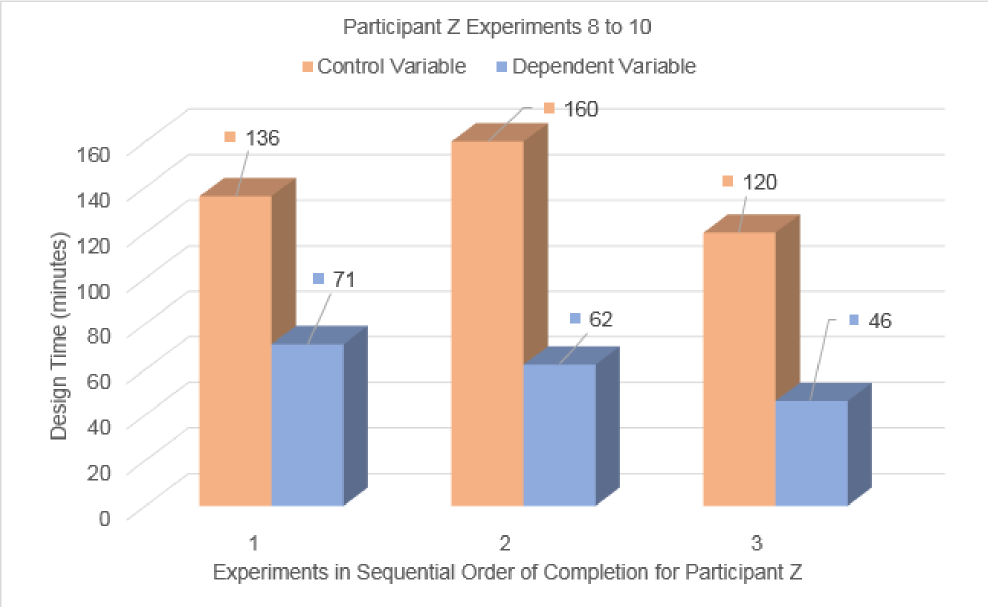

Figure 24 showing a summary of participant Z design times

(See Appendix D for source data)

An average of all three experiment design times represented a 57% improvement when compared to the average control variable time.

4.4.14. Significance Testing of Objective Two Design Experiments

A t-test can be used to determine whether there is a significant difference between two datasets (Saunders, Lewis, & Thornhill, 2012). It does this by comparing the mean of all results in each dataset. A more appropriate t-test in this instance is the paired t-test. This compares the mean of two datasets that are related, in this case a before intervention or control variable and an after intervention or dependent variable (Godwill, 2015). Paired t-testing can then be used in hypothesis testing. In this case, the null hypothesis would state that there would be no significant difference between control and dependent design times.

	Control Variable (Current Methods)	*Dependent Variable (New Methods)*
Mean	108.600	62.800
Variance	920.267	317.511
Observations	10.000	10.000
Pearson Correlation	0.010	
df	9.000	
t Stat	4.135	
P(T<=t) one-tail	0.001	
t Critical one-tail	1.833	
P(T<=t) two-tail	0.003	
t Critical two-tail	2.262	
Confidence interval of 95%	70.856	
	20.744	

Figure 25 showing the results from a paired t-test of objective two pre- and post-intervention design times

Figure 25 shows the results from the paired t-test. The probability or p value is a measure of how probable the results would occur through chance alone. A value of less than 0.05 would mean that the difference between control and dependent variables is a '*statistically significant relationship'* (Saunders, Lewis, & Thornhill, 2012). The two-tailed t statistic was measured at 4.135 resulting in a p value of 0.003 which was less than the 0.05 threshold. This means that the differences are significant, that the null hypothesis can be rejected and that the alternative hypotheses, 'the use of new CAD tools will lead to a significant decrease in design modelling lead time' and that 'a decrease in design lead time will lead to an increase in design output' can be accepted.

A confidence interval is a range of values that one can be confident will contain the true mean difference in design improvement time. Figure 25 shows that there is a 95% confidence interval that the true mean improvement in design time lies somewhere between 21 and 71 minutes.

4.4.15. Summary of Objective Two Design Experiments

A summary of all control and intervention experiments can be seen in Figure 26. Each individual point represents an experiment. The yellow line represents control experiment design times. The orange, grey and blue lines represent participant intervention experiment design times. The measured design times for all three intervention participants were lower than the measured control time. As all the experiments were based on a within group design using repeated measures (see section 3.3.4), participant familiarity with experiments was observed. After the initial experiments, design times begin to continuously drop as participants became more familiar with the new CAD tools.

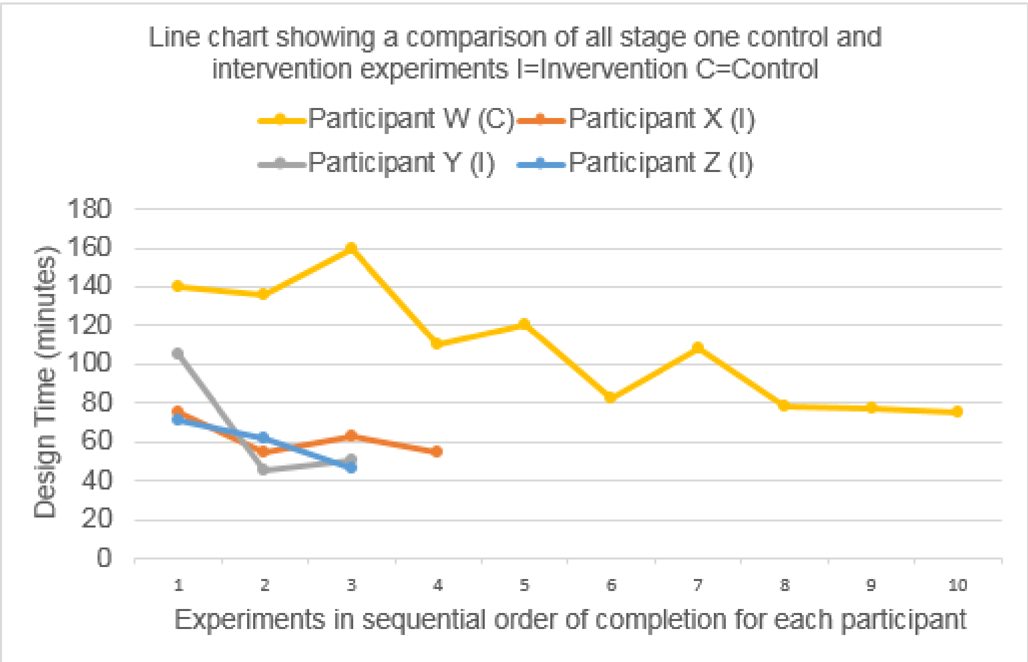

Figure 26 showing a comparison of control and intervention experiments

(See Appendix D for source data)

Some experiment design times increased marginally depending on the complexity of the design. Figure 27 shows a box plot of the distribution of control and intervention design times. The box plot shows that both the intervention times and the overall distribution of intervention times were reduced. This suggests that the intervention experiments were more closely managed than the control experiments.

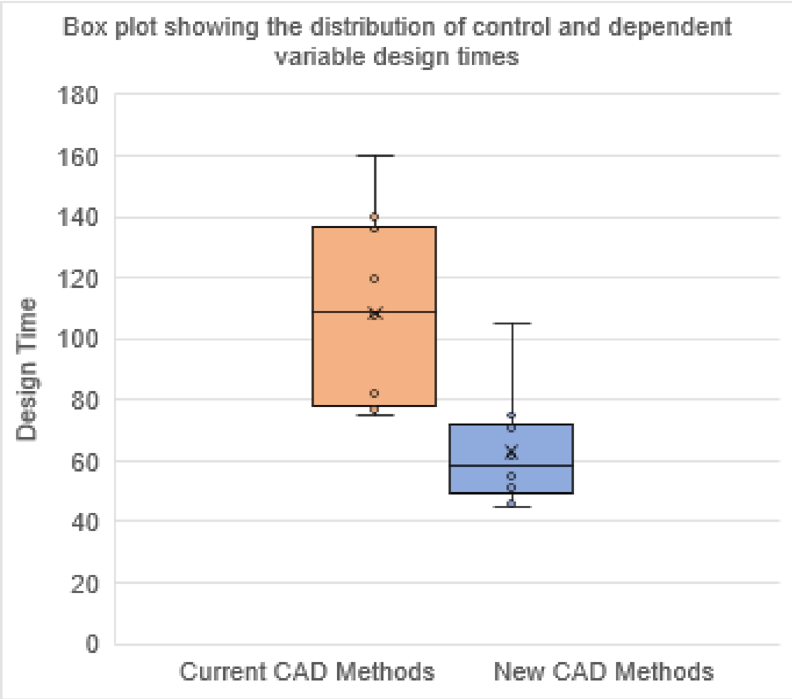

Figure 27 showing a comparison of control and intervention experiments

(See Appendix D for source data)

An average of all intervention experiment design times represented a 38% improvement when compared to the average of all control experiment design times. This represents a significant improvement in design time when compared to design times using current CAD methods and clearly shows that the intervention worked. Objective two stated that the current design output is ten tools per week and set a new target of twenty tools per week. To achieve this, stage one design times would have to be reduced by a minimum of 50%. Although the intervention was partially successful with an average improvement of 38%, it failed to achieve the new target of a 50% improvement. Figure 28 shows a summary of the results from objective two.

Current design output	10 tools/week
Target design output	20 tools/week
Target design time improvement to achieve 20 tools/week	50%
Actual improvement achieved	38%

Figure 28 showing a summary of the results from objective two

4.5. Findings and Analysis of Objective Three

Objective three measured the improvement in lead time in the stage two drafting design process by the use of new drafting CAD templates and section views. A paired t-test was used to determine whether to reject or not reject the null hypotheses. A null hypothesis would state that there would be no significant difference between the use of current drafting methods and new drafting methods. The experimental results and analysis will now be presented in the order that each participant completed them.

4.5.1. Experiment One

Experiment one was performed by research participant X. Figure 29 shows the results from experiment one. The control variable using current CAD methods for this experiment was measured at 530 minutes. The dependent variable using new CAD methods for this experiment was measured at 451 minutes. This represents a 15% improvement in design time.

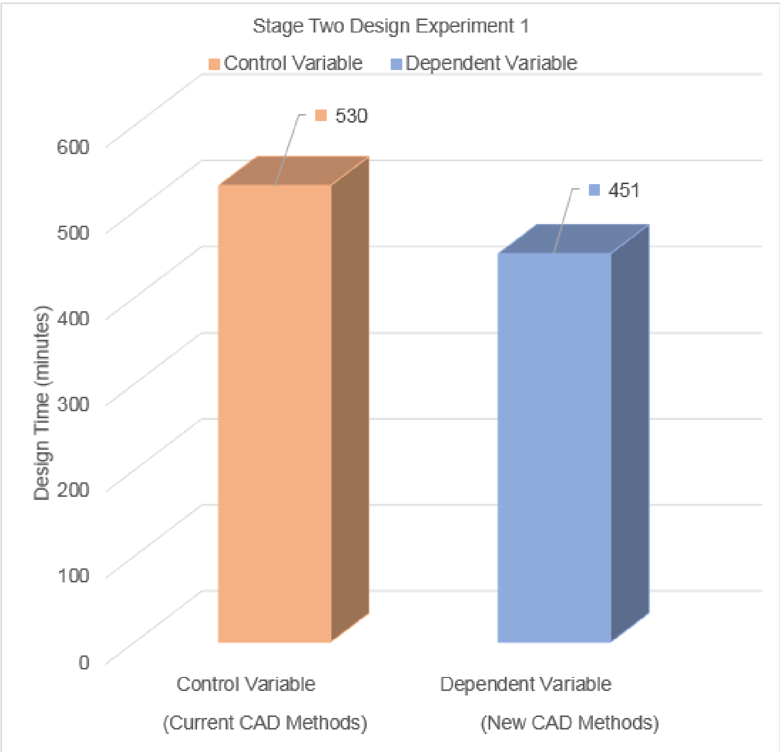

Figure 29 showing experiment 1 design times

(See Appendix E for source data)

4.5.2. Experiment Two

Experiment two was performed by research participant X. Figure 30 shows the results from experiment two. The control variable using current CAD methods for this experiment was measured at 537 minutes. The dependent variable using new CAD methods for this experiment was measured at 425 minutes. This represents a 21% improvement in design time.

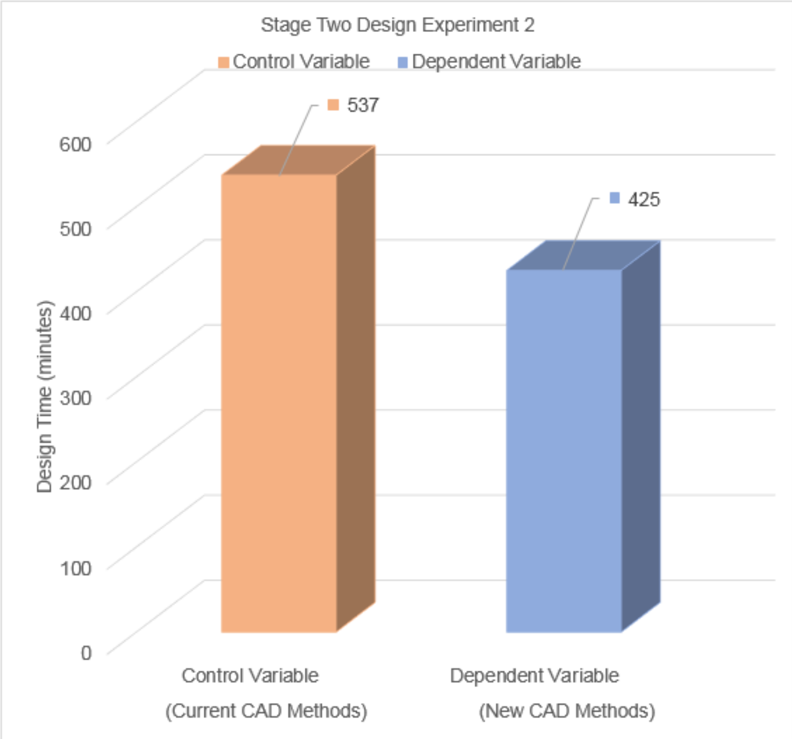

Figure 30 showing experiment 2 design times

(See Appendix E for source data)

4.5.3. Experiment Three

Experiment three was performed by research participant X. Figure 31 shows the results from experiment three. The control variable using current CAD methods for this experiment was measured at 570 minutes. The dependent variable using new CAD methods for this experiment was measured at 397 minutes. This represents a 30% improvement in design time.

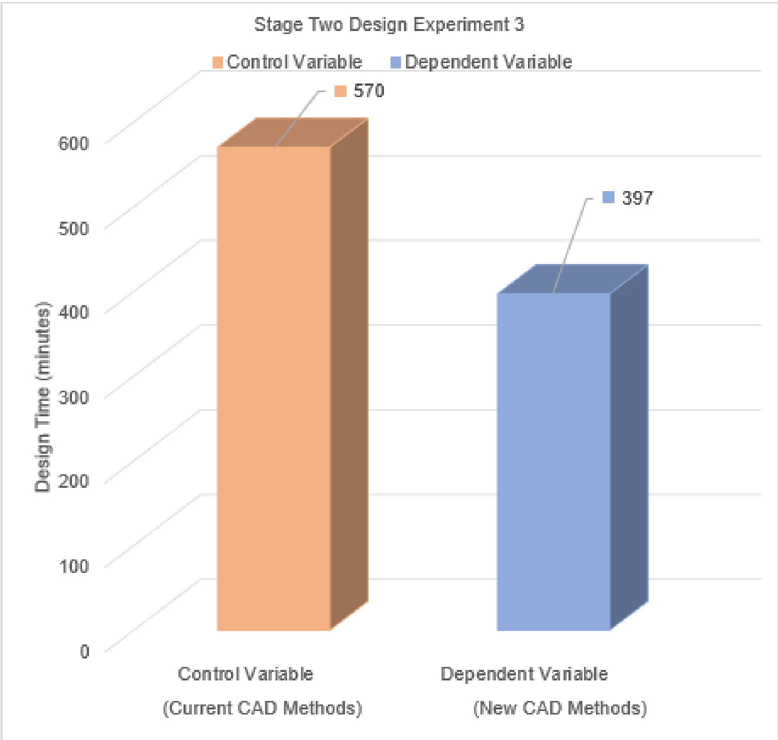

Figure 31 showing experiment 3 design times

(See Appendix E for source data)

4.5.4. Experiment Four

Experiment four was performed by research participant Y. Figure 32 shows the results from experiment four. The control variable using current CAD methods for this experiment was measured at 525 minutes. The dependent variable using new CAD methods for this experiment was measured at 362 minutes. This represents a 31% improvement in design time.

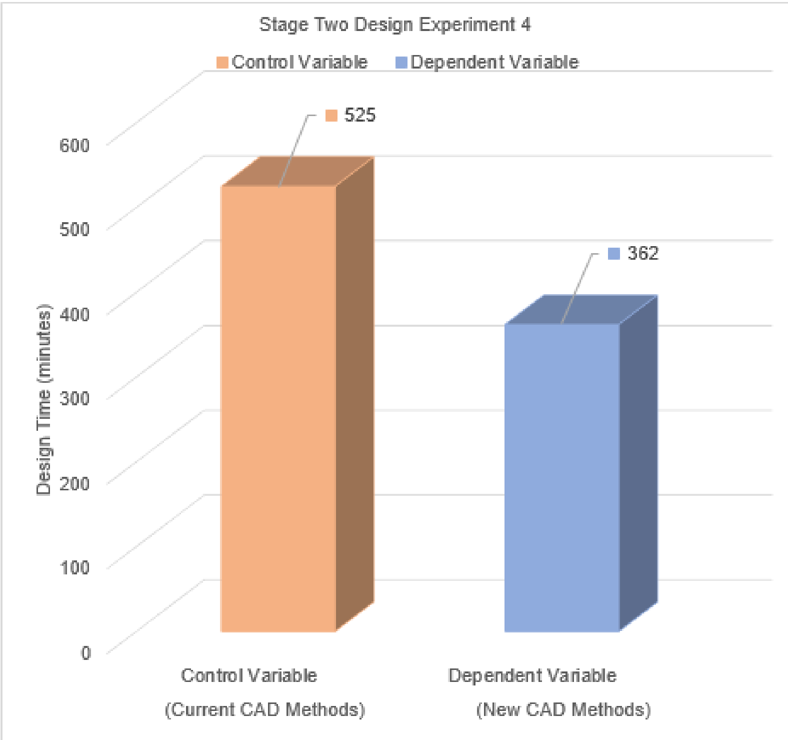

Figure 32 showing experiment 4 design times

(See Appendix E for source data)

4.5.5. Summary of Participant X Experiments

The four experiments of participant X showed an improvement in design time. See Figure 33.

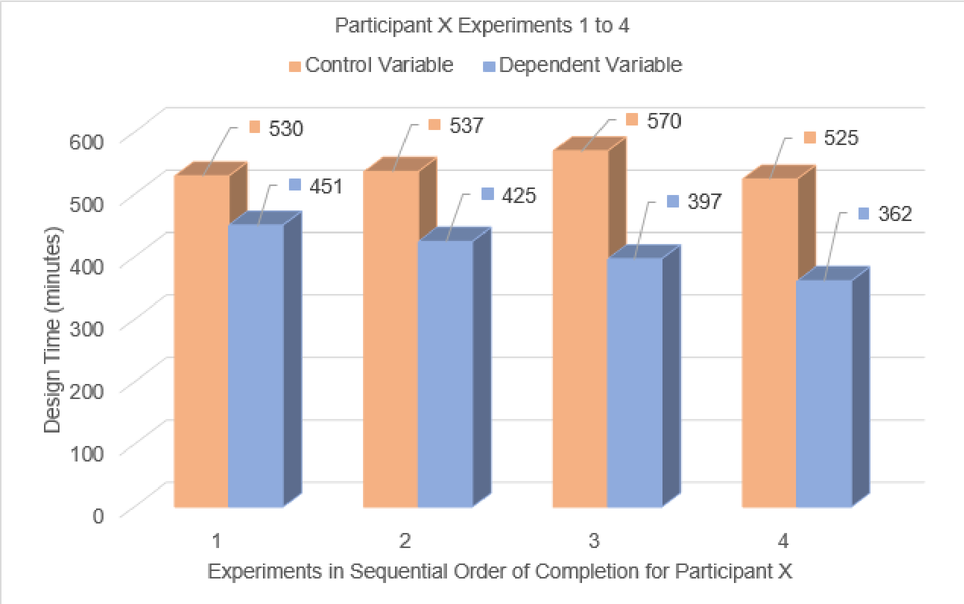

Figure 33 showing a summary of participant X design times

(See Appendix E for source data)

An average of all four experiment design times represented a 24% improvement when compared to the average control variable time.

4.5.6. Experiment Five

Experiment five was performed by research participant Y. Figure 34 shows the results from experiment five. The control variable using current CAD methods for this experiment was measured at 525 minutes. The dependent variable using new CAD methods for this experiment was measured at 449 minutes. This represents a 14% improvement in design time.

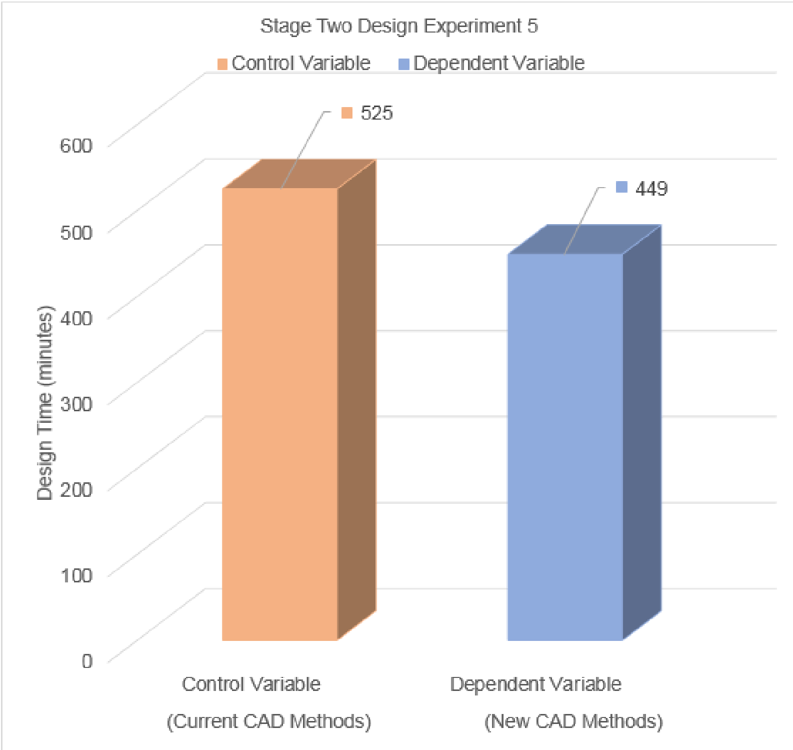

Figure 34 showing experiment 5 design times

(See Appendix E for source data)

4.5.7. Experiment Six

Experiment six was performed by research participant Y. Figure 35 shows the results from experiment six. The control variable using current CAD methods for this experiment was measured at 495 minutes. The dependent variable using new CAD methods for this experiment was measured at 432 minutes. This represents a 13% improvement in design time.

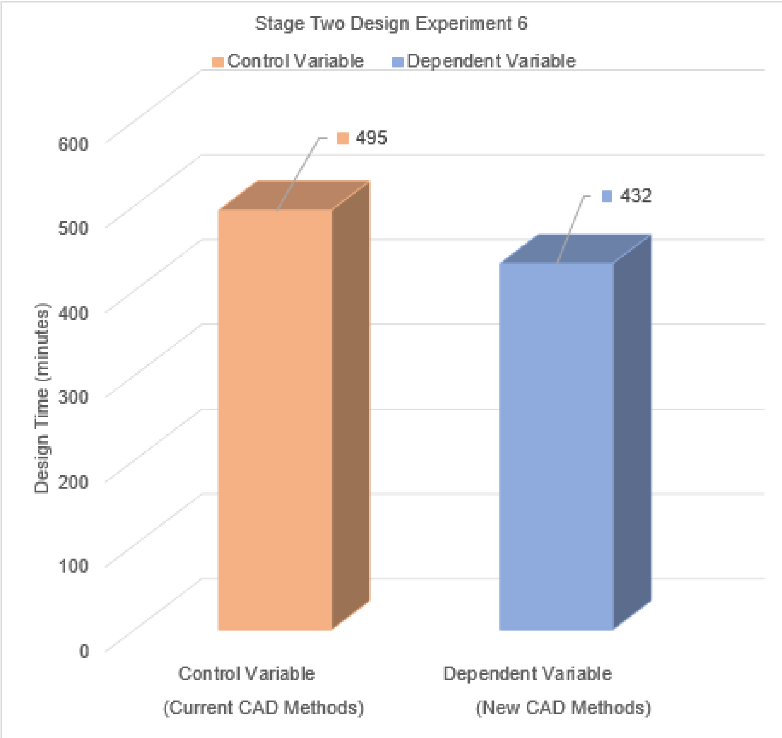

Figure 35 showing experiment 6 design times

(See Appendix E for source data)

4.5.8. Experiment Seven

Experiment seven was performed by research participant Y. Figure 36 shows the results from experiment seven. The control variable using current CAD methods for this experiment was measured at 456 minutes. The dependent variable using new CAD methods for this experiment was measured at 412 minutes. This represents a 10% improvement in design time.

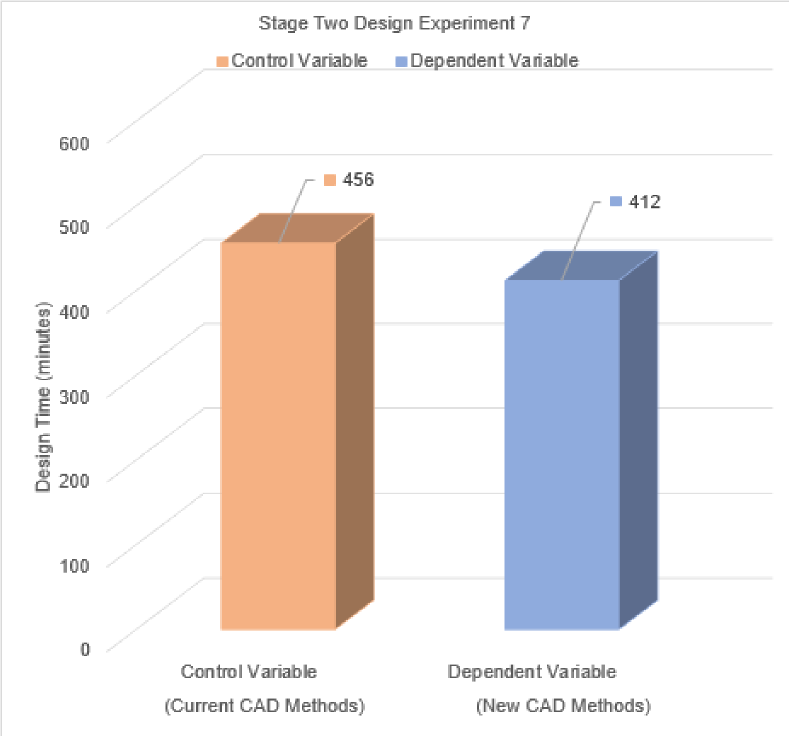

Figure 36 showing experiment 7 design times

(See Appendix E for source data)

4.5.9. Experiment Eight

Experiment eight was performed by research participant Y. Figure 37 shows the results from experiment eight. The control variable using current CAD methods for this experiment was measured at 585 minutes. The dependent variable using new CAD methods for this experiment was measured at 459 minutes. This represents a 22% improvement in design time.

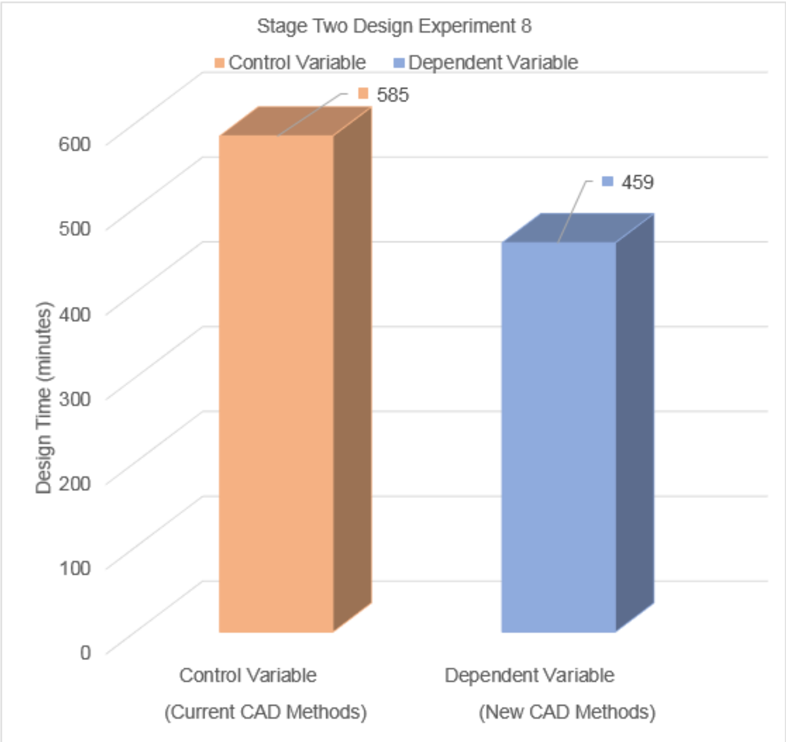

Figure 37 showing experiment 8 design times

(See Appendix E for source data)

4.5.10. Experiment Nine

Experiment nine was performed by research participant Y. Figure 38 shows the results from experiment nine. The control variable using current CAD methods for this experiment was measured at 570 minutes. The dependent variable using new CAD methods for this experiment was measured at 427 minutes. This represents a 25% improvement in design time.

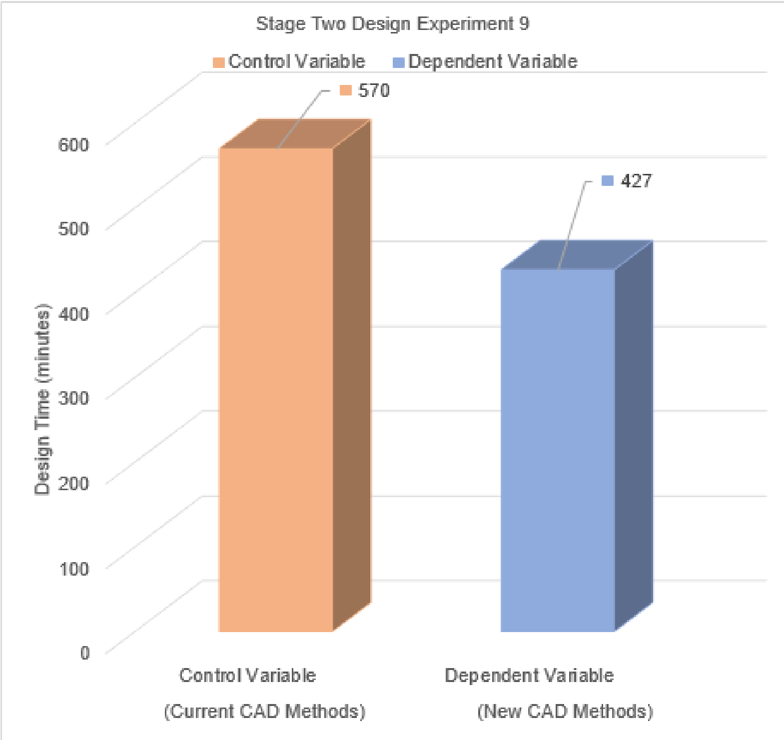

Figure 38 showing experiment 9 design times

(See Appendix E for source data)

4.5.11. Summary of Participant Y Experiments

The five experiments of participant Y showed an improvement in design time. See Figure 39.

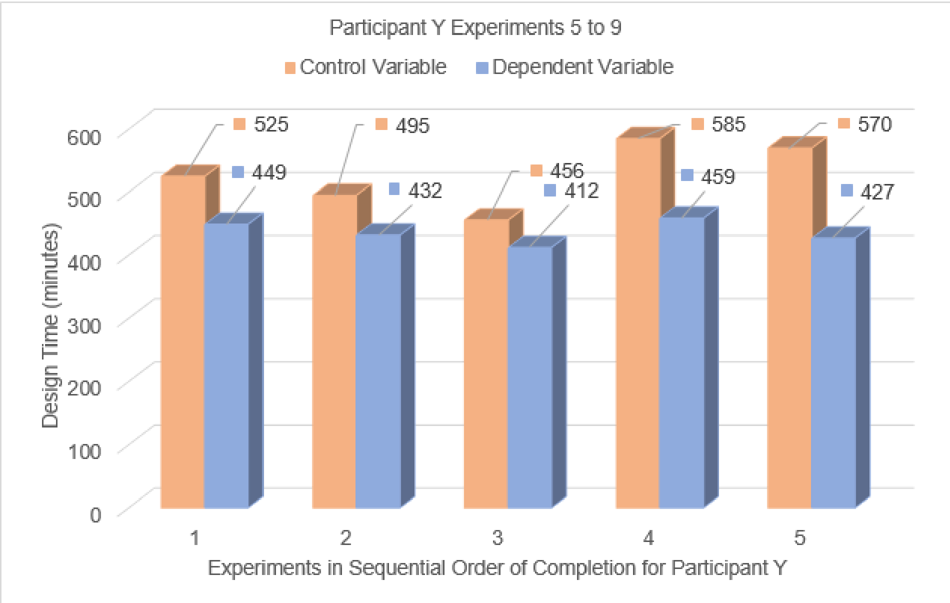

Figure 39 showing a summary of participant Y design times

(See Appendix E for source data)

An average of all five experiment design times represented a 17% improvement when compared to the average control variable time.

4.5.12. Experiment Ten

Experiment ten was performed by research participant Z. Figure 40 shows the results from experiment ten. The control variable using current CAD methods for this experiment was measured at 655 minutes. The dependent variable using new CAD methods for this experiment was measured at 466 minutes. This represents a 29% improvement in design time.

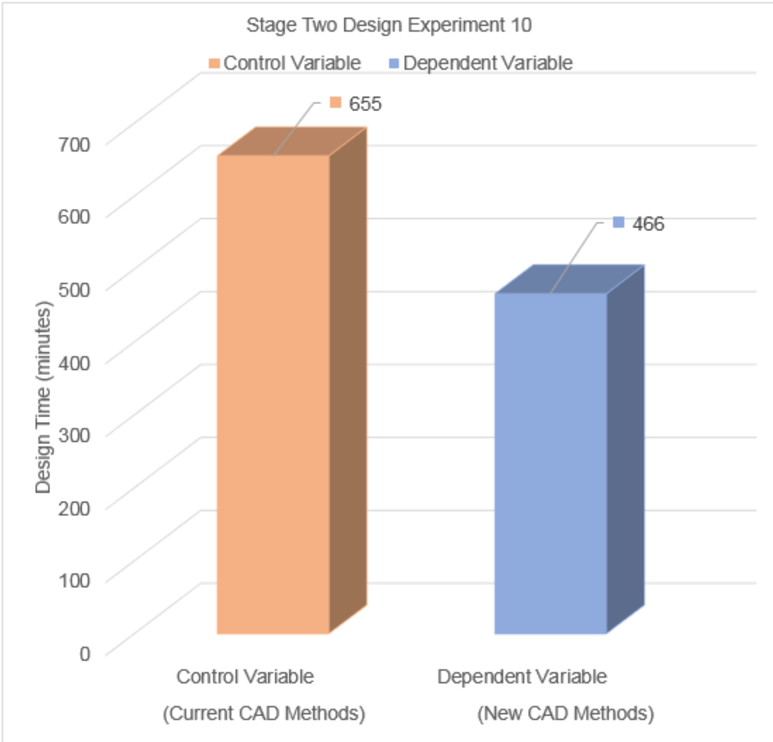

Figure 40 showing experiment 10 design times

(See Appendix E for source data)

As this experiment was the only intervention experiment participant Z was involved with, no summary is required.

4.5.13. Significance Testing of Objective Three Design Experiments

A paired t-test was performed to determine whether the difference between the mean pre-intervention control time and mean post-intervention dependent time was statistically significant, see Figure 41.

	Control Variable (Current Methods)	*Dependent Variable (New Methods)*
Mean	544.800	428.000
Variance	2939.956	997.111
Observations	10.000	10.000
Pearson Correlation	0.417	
df	9.000	
t Stat	7.373	
P(T<=t) one-tail	0.00002	
t Critical one-tail	1.833	
P(T<=t) two-tail	0.00004	
t Critical two-tail	2.262	
Confidence interval of 95%	152.637	
	80.963	

Figure 41 showing the results from a paired t-test of objective three pre-and post-intervention design times

The two-tailed t statistic was measured at 7.373 resulting in a p value of 0.00004. This is close to zero and is much less than the 0.05 threshold which means that the differences are statistically significant. The null hypothesis can therefore be rejected and the alternative hypothesis that 'the use of new CAD tools will lead to a significant decrease in design drafting lead time' can be accepted.

A confidence interval was also calculated. One can be 95% confident that the true mean improvement in design time lies somewhere between 81 and 153 minutes.

4.5.14. Summary of Objective Three Design Experiments

A summary of all control and intervention experiments for objective three can be seen in Figure 42. Each point represents an experiment. The green and yellow lines represent control experiment design times. Participant Z was only involved with one intervention experiment, labelled as a blue dot in Figure 42. Participant Z also performed most of the control experiments labelled as a green line below. The orange and grey lines represent participant intervention experiment design times. The measured design times for all three intervention participants were marginally lower than the measured control time. Participant familiarity due to the within group design using repeated measures was also observed throughout these experiments and can be seen as a downward trend in Figure 42.

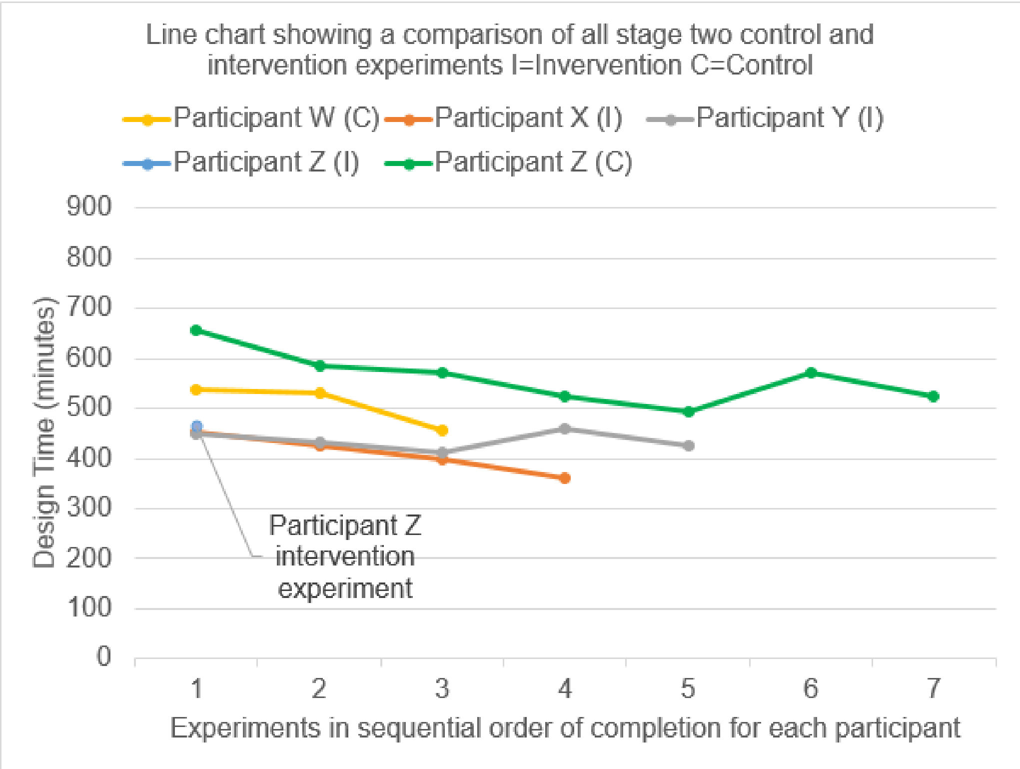

Figure 42 showing a comparison of control and intervention experiments

(See Appendix E for source data)

Figure 43 shows a box plot of the distribution of control and intervention design times. The box plot shows that although the intervention times were reduced, the distribution of both control and intervention times were similar. This suggests that although the intervention reduced design time, experiments within the control and intervention groups were taking similar times to complete.

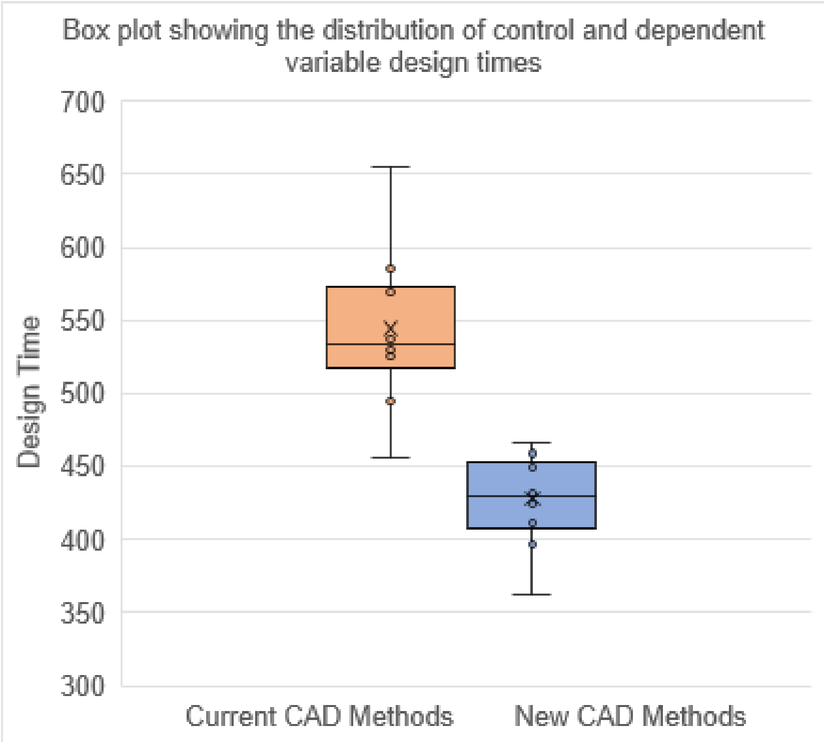

Figure 43 showing a comparison of control and intervention experiments

(See Appendix E for source data)

An average of all intervention experiment design times represented a 21% improvement when compared to the average of all control experiment design times. Although this represents an improvement in design time when compared to current CAD methods, it was less than the previous objective and much lower than expected. The current design output for this objective is eight tools per week with a new target of sixteen tools per week. To achieve this output, design times would have to be reduced by 50%. The intervention helped to reduce design times by an average of 21% but failed to meet the new target of a 50% improvement. Figure 44 shows a summary of the results from objective three.

Current design output	8 tools/week
Target design output	16 tools/week
Target design time improvement to achieve 20 tools/week	50%
Actual improvement achieved	21%

Figure 44 showing a summary of the results from objective three

Chapter 5

5. Interpretation and Conclusions

5.1. Introduction

This chapter will begin by critically evaluating the adopted research method. It will then present conclusions about the research objectives in relation to the literature review in chapter two. Conclusions about the research hypotheses will then be discussed in relation to the literature review followed by overall conclusions. The chapter will conclude with a discussion of limitations of the research method and opportunities for further research.

5.2. Critical Evaluation of the Research Method

The overall aim of the research was to evaluate and improve the design process within Henrob. The design process uses CAD to generate customer product designs in a two-stage process. Improvements within these two stages would lead to reduced design lead times and increase design output. The experimental method using phantom and drafting templates was chosen as the most appropriate method as the variable that was measured within each stage was lead time. This lends itself to a pre and post-test comparison of design time using experiments. However, some difficulties arose during experiments for both objectives.

5.2.1. Familiarity due to Limited resources

Due to limited resources, all control experiments for objective two were performed by participant W. For objective three, three control experiments were performed by participant W and seven were performed by participant Z. Participant familiarity was observed with control experiments for both objectives. This can be seen in Figure 26 and Figure 42 as a downward trend in control design time. Although familiarity could lead to a reduction in internal validity, the effects that were observed were small. This problem was also partially offset by familiarity within the intervention experiments.

5.2.2. Selection of Typical Case Samples

Some design samples were more complex than others resulting in slightly longer design times. This can be seen as a slight upward trend in some control and intervention experiment times for both objectives in Figure 26 and Figure 42. As the affect was small, it did not have a large impact on the research.

5.2.3. Participant experience and Other Minor Issues

Although participants were all qualified, some had more design experience than others. Participant X had the most experience and this is reflected in Figure 26 and Figure 42 as lower intervention experiment times than other participants that completed similar experiments for both objectives. This was not considered an issue as, on average, all experiments resulted in lower design times.

Interruptions by other employees that were unaware of the experiments taking place were kept to a minimum by the researcher intervening whenever possible.

5.3. Conclusions about the Research Objectives

5.3.1. Conclusions of Objective One

Objective one used process mapping to map the current state of the tool design process within the design office at Henrob. Khan, et al., (2011) argued that lean methods like process mapping and value stream mapping could be used to reduce waste successfully when applied to new product development environments. It does this by establishing a visual map of information flow and highlights where bottlenecks and other wastes are occurring. Figure 10 shows the map for stage one design. Although this map shows that waste was occurring at the beginning of the process concerning data sheets, during engineering validation and at the approval stage, the important time and error wastes were occurring during the design modelling stage. Figure 11 shows the map for stage two design. Again, there were error wastes at the beginning of the process, error and over processing wastes at the approval stage but the important time, error and talent wastes involved the production of drawings.

Baines, Lightfoot, Williams, & Greenough (2006) argued that within product development, value is created by establishing information flow. If the modelling and drafting parts of the stage one and stage two design process could be streamlined by improving the flow of information and reducing bottlenecks, a reduction in design lead time would be possible.

5.3.2. Conclusions of Objective Two

Objective two measured the improvement in stage one modelling design lead time. A summary of the results can be seen in Figure 28. To increase design output from ten to twenty tools per week, a design time improvement of 50% would be required. Actual design time improvement was measured at 38%.

Although the objective failed to meet its target of 50%, Henrob still considered this as an acceptable improvement.

Lindlöf, Söderberg and Persson (2012) argued that the transfer and reuse of existing knowledge is important when applying lean techniques to product development. Objective two added value to the stage one design process by capturing existing modelling information and adding this and new information into phantom assembly templates that could be reused on multiple occasions. This helped to reduce design times and improve information flow but more importantly, the use of phantom assembly templates increased the quality of designs. Research by Tan and Vonderembse (2006) and Vishwas, Vinyas and Puneeth (2016) both agree that the use of CAD and CAD templates can lead to reduced lead times and improved product quality. This was achieved by including as much information as possible that had already been pre-checked within the phantom assembly templates.

Although research by Tiwari, Jain and Tandon (2014) also argue that the use of CAD templates can reduce lead times by automating some of the preliminary design tasks, one disadvantage of using phantom assembly templates is the need for these documents to be brought under some form of document revision control. This is because phantom assemblies contain revision controlled documents themselves. Revision controlled documents are those that require formal control within an organisations quality management system. This will have time and cost implications for the design process but is necessary to ensure phantom assembly templates are to the latest standards.

5.3.3. Conclusions of Objective Three

Objective three measured the improvement in stage two drafting design lead time. Figure 44 shows a summary of the results. To increase design output from eight tools per week to sixteen tools per week, an improvement of 50% would be required. This objective measured actual improvement of design time at 21%.

Although this improvement also failed to meet the objective target of 50%, Henrob still considered this an acceptable improvement but was much lower than expected.

Research by Letens, Farris and Van Aken (2011) suggest that it is less difficult employing lean methods in a product based manufacturing environment than it is in the more complex intangible product development environment. This was certainly true of both objectives but more so when considering objective three due to the high complexity of the drafting process.

This part of the design process is labour intensive with many more tasks to complete when compared to stage one design modelling from the previous objective. The average intervention time for stage one modelling was 63 minutes, see Figure 25, whereas the average stage two intervention drafting time was 428 minutes, see Figure 41. On average, drafting was taking almost seven times as long as modelling due to the complex nature of this part of the design process. Simmons, Phelps and Maguire (2012) also agree that drafting is the most complex part of the design process, a fact that is well documented throughout the manufacturing indusrty.

The smaller improvement in design lead time when compared to objective two was partially offset by an increase in drafting quality. Intervention drafting templates contained four sheets of additional information when compared to control drafting templates, see Figure 7. This capture of knowledge helped to improve the flow of drawings through the design process and also reduced the number of errors occurring at this stage.

All of the improvements observed in objective three were primarily due to the use of drafting templates. The pilot study highlighted a research design flaw with the fastener system and consequently, this CAD tool was not used in the research (see section 3.4.5). Section views added more complexity to the process with little added value. In some cases, section views were increasing design times.

The results from this objective also agreed with research by Tiwari, Jain and Tandon (2014) and Vishwas, Vinyas and Puneeth (2016) when considering the benefits of using CAD and CAD templates. An additional advantage of using CAD drafting templates is that, unlike phantom assembly templates, drafting templates do not contain any controlled documents and therefore they do not require revision control.

5.4. Conclusions about the Research Hypotheses

The research generally agreed with both hypotheses, ‘the use of new CAD tools would lead to a significant decrease in design modelling and drafting lead time’. This also implies agreement with the third hypothesis, ‘a decrease in design modelling and drafting lead time will lead to an increase in design output’. Although each research objective did not meet its target, the research could still be considered partially successful in that it:

- reduced overall product lead time and improved design output.
- successfully used lean methods to map the design process.
- reduced the number of errors.
- reduced processing time and improved information flow.
- improved information quality.
- highlighted one part of the design process that was still underperforming. The information flow between the design office and engineering was still a source of error and waiting wastes. This became apparent at the objective two design stage as some stage one research experiments were put on hold whilst engineering validated the designs. Although this

had little effect on the final research results, it is still a part of the design process that could be improved.

One additional positive outcome of the research was the creation of a standardised library of tools. The library consisted of the ten experiment designs and the addition of another six designs. The use of this library could reduce lead times considerably from the current twelve weeks to an estimated lead time of two weeks. This is possible as standard long lead time items can be purchased in advance. Using a library would also have a substantial impact on design lead time as this could be completed much earlier in the process. It would also reduce the number of different designs required by customers with a corresponding reduction in design work load.

5.5. Overall Conclusions

In general, the research could be regarded as a success. Objective one used process mapping to successfully map the current state of the design process. This highlighted problem areas that were then addressed in objectives two and three. Both objectives reduced design lead time by 38% and 21% respectively. This is a considerable saving in time with a corresponding increase in design output. The most important outcome from both objectives was creation of real value by capturing and retaining existing and new knowledge through the use of design templates. This had a number of effects on the design process. This new knowledge capture:

- reduced the overall design workload and improved work and information flow by reducing the number of individual tasks necessary to complete a final design.
- increased the quality of the modelling and drafting design processes by ensuring templates contained pre-determined and pre-checked information that could then be reused on multiple occasions.
- reduced the number of error, waiting and over-processing wastes associated with traditional design methods.

5.6. Limitations of the Study

Henrob has many different design functions across multiple global sites. Due to practical and time constraints, the study was limited to the tool design process in the UK. However, the findings from the study could be generalised to other Henrob companies with both similar and different design processes. It might be more difficult to externally generalise the specific findings to other organisations. However, given that the use of CAD templates is a well-known lead time improvement tool (Vishwas, Vinyas and Puneeth, 2016), this in principle is also possible.

The research was based around creating new designs using existing components and then drafting those designs. Although this is regarded as a valid design task, one limitation of the study was the exclusion of more analytical and creative design time from the experiments. This was due to the complex nature of this type of design which would have made the experiments overly complicated.

Another limitation of the study was the selection of design samples to perform experiments on. The research concentrated on one type of tool assembly. However, Henrob designs and manufactures many different types of tool assembly, all with differing degrees of complexity.

5.7. Opportunities for Further Research

The research was based around the use of new CAD template tools to help streamline the stage one and two design process. To assist in future research, CAD templates should be further developed to include more phantom assemblies under revision control. Drafting templates could also be developed by including more information to cover a more extensive range of designs. Analytical and creative design should also be included in any future research to ensure more accurate design times.

Further research might focus on increasing the sample size and include more product types within the sample. This would have the effect of broadening the original research, further improving the design process and simplifying generalisability. This could lead to similar lead time improvements within design environments in other Henrob companies.

Although the experimental method was an appropriate research method when applied to the design process, any similar future research could benefit from the addition of other research methods. A mixed method strategy could include experiments and a survey by questionnaire or structured interviews. As well as quantitative data, this type of strategy could also provide the researcher with new insightful qualitative data on how well the research was performed, how the research could be improved and finally, how the overall design process could be further improved.

Chapter 6

6. Recommendations

The research concentrated on the use of CAD templates to help improve information flow through the design office. It is recommended that Henrob continue developing CAD template tools for tool assembly design and continue the research using these improved templates for other types of product design.

Henrob should continue to prioritise the high value of knowledge capture and information flow within the design office. Templates are one way of achieving this. It is recommended that Henrob investigate other ways of achieving this, for example, through the use of product data management software. This type of software adds a high degree of control to centrally stored data and can lead to significant improvements in work flow and lead times.

Looking towards the future, Hirz, Rossbacher and Gulanová, (2017) predict that visualisation of designs will become increasingly important. It is therefore recommended that Henrob investigate other more innovative and novel ways of improving the overall design process. Augmented reality, whereby CAD models of a particular product can be superimposed over a real product becomes possible (Schmalstieg & Hollerer, 2016). This could be used as an important early error checking tool, leading to further reduced defect and waiting wastes. Moghaddam & Nof (2015) stressed the importance of integrating different digital systems in the new collaborative factories of the future. The integration of virtual reality simulation and CAD should also be explored. This helps designers to visualise final product designs and reduces the number of design iterations, a form of waiting waste.

Another concept that Henrob should continue exploring is Industry 4.0 (Gilchrist, 2016). This is a general industrial trend towards greater interconnectivity by implementing more automation, simulation, mixed reality technologies and data management, all of which could further improve the design process (Shafiq, Sanin, Szczerbicki, & Toro, 2016).

6.1. Implementation Plan

There are continued benefits from this research for the organisation. Henrob is currently in the process of creating a new standardised library in addition to the library created through the research. It has been proposed to use the new CAD templates to ensure the highest standards are maintained. In this case, the increased quality is considered more important than the reduced design lead times. Therefore, an implementation plan has been created to capitalise on the benefits of the research, see Figure 45. Phantom assembly templates should be finalised by the end of November and will have to come under revision control by the design office. Drafting templates will then be finalised. Due to the complex nature of drafting, it is proposed that more than one drafting template will be needed to cover a range of products. The fastener system was not used during the research but this new CAD tool will be needed to complete product designs and has been included in the plan. Guidelines will be created by the technical publications department. The researcher will schedule and supervise training sessions early next year before rollout of the new templates in the UK design office.

If the use of the new templates is successful, then the researcher will consider proposing a rollout in both the UK and Henrob Corp in the USA. The exploration of new CAD technology will run concurrently with the template implementation.

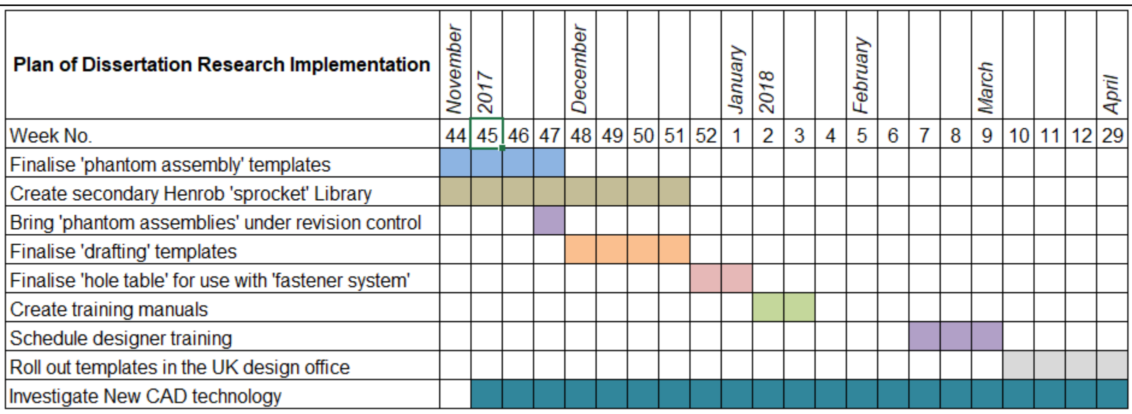

Figure 45 showing a Gantt chart of the research implementation plan

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Appendices

Appendix A

An example of a procedure to create an intervention model used in the research. This relates to objective two, design stage one.

1. Introduction

This document outlines the procedure for creating a Henrob stage one intervention model. Stage one design is the equivalent of Henrob stage four design.

2. Prerequisites

All intervention tool models will be stored at the location below.

H:\Wip_Do\OTHER PROJECTS\VSM\STAGE 1 TOOL MODELS\INTERVENTION

All intervention models will use phantom assemblies. They can be found at the location below.

H:\PHANTOM ASSEMBLIES

This procedure should be used alongside the tool datasheet and the phantom modelling design guidelines.

XpresRoute generated T tube conduit and XpresRoute generated Harting conduit should be present in the intervention model.

No screws, nuts or washers should be present in the intervention model (except those that are present in sub-assemblies and phantom assemblies).

3. Intervention Model Creation Procedure

3.1. Create a new Henrob Assembly from the solid edge start screen.

3.2. Name the file Jxxxxxx VSM I.asm (where xxxxxx is either the JA or JL number).

3.3. Save the file in H:\Wip_Do\OTHER PROJECTS\VSM\STAGE 1 TOOL MODELS\INTERVENTION\Jxxxxxx VSM I (where xxxxxx is either the JA or JL number).

3.4. Insert C frame into the assembly model. Ensure that the C frame is in the correct orientation. The C frame setter and die bores should be aligned with the Z axis. The Y axis should point toward the rear of the C frame. See Figure 1 below.

3.5. Use the die post phantom assembly guidelines to insert an L shaped die post, rocket shaped die post or wear plate phantom assembly. Check the datasheet for the correct die post part number. ***Do not disperse this assembly. Follow the on screen visual cues to add all relationships to all parts.*** Select the C frame and suppress the ground constraint. Move the C frame in the Z axis until the top face of the die is flush with XY plane. Then un-supress the C frame ground constraint See Figure 2 below.

3.6. Use the setter and front end phantom assembly guidelines to insert the setter front end phantom assembly. Check the datasheet for the correct setter front end part number. ***Disperse this assembly and add relationships to all parts using the guidelines.*** Ensure the feeder and setter are set to the correct angle.

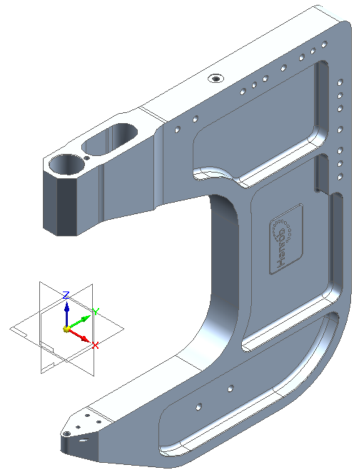


Figure 1 Insert C frame into assembly

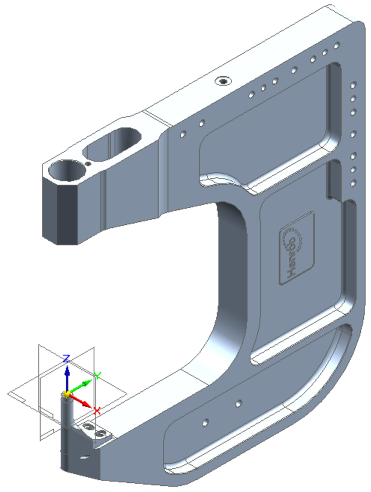


Figure 6 Align C frame with the assembly origin

3.7. Use the setter and front end phantom assembly guidelines to insert the setter front end phantom assembly. Check the datasheet for the correct setter front end part number. ***Disperse this assembly and add relationships to all parts using the guidelines.*** Ensure the feeder and setter are set to the correct angle.

3.8. Set the feeder/setter to the correct nose to die gap.

3.9. Add spacers above and below the C frame setter head as required.

3.10. Insert the T tube steady bracket, MA1144.

3.11. Insert magazine mounting brackets.

3.12. Use the sub-assembly phantom assembly guidelines to insert the magazine assembly, either PHA-MA530379 or PHA-MA530380. Check the datasheet for the correct magazine part number. ***Do not disperse this assembly. Follow the on screen visual cues to add all relationships to all parts.***

3.13. Use the sub-assembly phantom assembly guidelines to insert the Harting bracket and

Harting quick connect MA530275. ***Do not disperse this assembly. Follow the on screen visual cues to add all relationships to all parts.*** (Note that if the Harting requires a special bracket, then insert bracket and Harting quick connect manually).

3.14. Constrain the Harting quick connect feeder half, MA530275-2 to the mating half, MA530275.

3.15. Use the sub-assembly phantom assembly guidelines to insert the cable bulkhead assembly. Check the datasheet for the correct cable bulkhead part number. ***Do not disperse this assembly. Follow the on screen visual cues to add all relationships to all parts.***

3.16. Use the sub-assembly phantom assembly guidelines to insert the tooling bracket assembly, either PHA-MA1026 or PHA-MA1027. Check the datasheet for the correct bracket part number. ***Do not disperse this assembly. Follow the on screen visual cues to add all relationships to all parts.***

3.17. If required, use the sub-assembly phantom assembly guidelines to insert a dumbbell tooling bracket assembly, either PHA-MA1028 or PHA-MA1030. *Please note that there are a number of different tooling bracket, dumbbell and adaptor plate combinations to choose from. Check the datasheet for the correct dumbbell/tooling bracket/adaptor plate part number.* ***Do not disperse this assembly. Follow the on screen visual cues to add all relationships to all parts.***

3.18. Insert air tube F4091-C, 1m.

Appendix B

An example of a procedure to create a control draft used in the research. This relates to objective three (design stage two).

1. Introduction

This document outlines the procedure for creating a Henrob stage two control draft. Stage two drafting is the equivalent of Henrob stage five drafting.

2. Prerequisites

All control tool drafts will be stored at the location below.

H:\Wip_Do\OTHER PROJECTS\VSM\STAGE 2 TOOL DRAFTS\CONTROL

This procedure should be used alongside the tool datasheet and robot direct mount drafting guidelines drawing number 3627 and pedestal mount drafting guidelines 3628.

This procedure will include instructions on how to complete the control model as well as instructions on how to complete the control draft.

3. Control Draft Creation Procedure

3.1. Create a new Henrob Tool Assy Draft from the solid edge start screen.

3.2. Name the file Jxxxxxx VSM C.dft (where xxxxxx is either the JA or JL number).

3.3. Save the file in H:\Wip_Do\OTHER PROJECTS\VSM\STAGE 2 TOOL DRAFTS\CONTROL\Jxxxxxx VSM C (where xxxxxx is either the JA or JL number).

3.4. Copy the relevant control model from the stage 1 control model folder and place in the corresponding control draft folder.

3.5. Open the control model. Add screws, nuts, washers and dowel pins to all equipment that require fastening. Use individual parts, then use the 'component pattern' command where necessary.

3.6. Insert labels H291044 (2), H2910921 (2), H2910925 (2), H2910930 (2), H291301 (3) and H29252 (1) to the model. For magazine tools, add H29250 (1).

3.7. For magazine tools, insert cables EA4072-xxxx, EA4073-xxxx, EA4081-xxxx, EA4083-xxxx, EA4098-xxxx, where xxxx is an appropriate length. Add M3 Schnorr washer P01161 (8) and M3 x 10 SHCS P0351 (8).

3.8. For pedestal tools, insert cables EA4072-xxxx, EA4073-xxxx, EA4083-xxxx, and 'Y' splitter 26-01544-xxxx, where xxxx is an appropriate length. Add M3 Schnorr washer P01161 (8) and M3 x 10 SHCS P0351 (8).

3.9. Ensure the Harting and T tube conduit occurrence properties are set to 'not to appear in the BOM'.

3.10. Insert earth cable E746007 (1m) and eyelet crimp E9229 (1).

3.11. Open the explode, render, animate environment in solid edge and create three new configurations called 'BRACKET EXPLODED', 'DIE POST EXPLODED' and 'SETTER

HEAD EXPLODED'.

3.12. Within the 'BRACKET EXPLODED' configuration, explode the adaptor plate, robot disc and fasteners and dowels. Hide all other parts and save.

3.13. Within the 'DIE POST EXPLODED' configuration, explode the die, die post and fasteners and pins. Hide all other parts and save.

3.14. Within the 'SETTER HEAD EXPLODED' configuration, explode the setter anti-rotation, feeder anti-rotation, spacers, lock nuts and fasteners and dowels. Hide all other parts and save.

3.15. The tool model is now complete and ready to draft.

3.16. Open the control draft that was created in step 3.1.

3.17. On sheet one, create two opposing isometric views of each side of the model. See Figure 1 below.

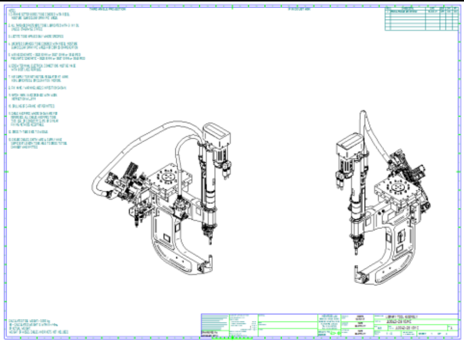


Figure 1

3.18. On sheet two, create three views, one side view (left side of sheet), one front view (centre of sheet) and one other side view (right side of sheet). See Figure 2 below.

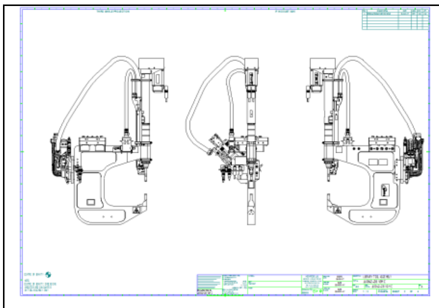


Figure 2

3.19. On sheet three, create two views, one side view, one front view or one other side view. More views may be added if the adaptor plate is not perpendicular to the die post. These views are for TCP dimensions. See Figure 3 below.

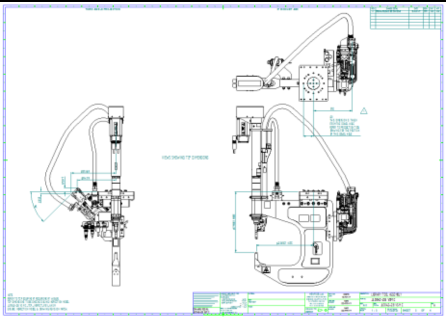


Figure 3

3.20. On sheet four, create a parts list from one of the isometric views on sheet one. See Figure 4 below.

Figure 4

3.21. Return to sheet one and add exploded views of the bracket, die post and setter head. Fully annotate each exploded view including view title and scale, part balloons, relevant screw torque values and other notes if required. Move and rescale views if necessary.

3.22. On sheet one, add detail views of the Harting quick connect unit and cable bulk head assembly. Fully annotate each view including view title and scale, part balloons, relevant screw torque values and other notes if required. Move and rescale views if necessary.

3.23. Ensure the thirteen general notes are present on sheet one.

3.24. On sheet two, add a section view of the setter that clearly shows the guide bush and punch retaining screws. Add a section view of the tooling bracket. Fully annotate each view including view title and scale, part balloons, relevant screw torque values and other notes if required. Move and rescale views if necessary.

3.25. Add a datum symbol and three dimensions that show the location of the centre of gravity of the complete tool.

3.26. On sheet three, for robot tools, add TCP dimensions from the top face and centre line of the die to the face and centre line of the adaptor plate. Add reference dimensions from the magazine dock face and location holes to the face and centre line of the adaptor plate. Add a timing dimension between the centre of the adaptor plate and a dowel hole, preferably in line the centre of the adaptor plate. Move and rescale views if necessary.

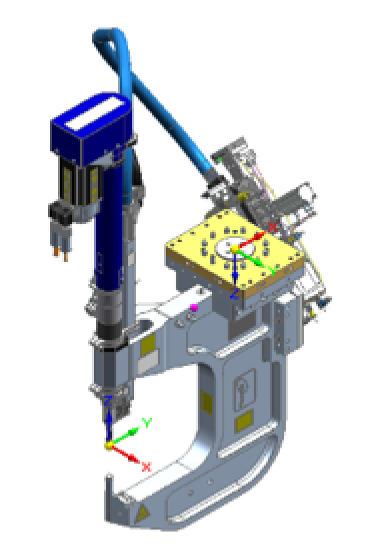
3.27. On sheet three, for pedestal tools, add TCP dimensions from the top face and centre line of the die to the face and centre line of the tooling bracket. Add a timing dimension between the centre of the tooling bracket and a dowel hole, preferably in line the centre of the tooling bracket. Move and rescale views if necessary.

Appendix C

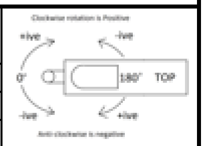
An example of a tool data specification sheet used in the research

Henrob VSM Stage One Control Model
Tool Data Specification Sheet

Tool number	JL0042-28	No. 7
Variable type	Control	
Design stage	One	
Objective	Two	
Part description	Part number	
C Frame	C5503504041004	
Die post	M179133-090	
Die	D000200S	
Die pins	M179206 (2)	
	M179207	
Anti-rotation	M18519	
Setter	RE250072XXBB	
Feeder	MA530406	
Spacers	M2719-XXXX, 5 (2), 20, 40,50,70	
Lock nuts	M1945 (2)	
AR brackets	MA1998	
	MA1999	
T tube bracket	MA1144	
Harting bracket	M1900938	
Harting	MA530275	
Magazine bracket 1	M1900661	
Magazine bracket 2	M1900660	
Magazine assembly	MA530380	
Strain relief	MA5975	
Bulk head	MA1140	
Tooling bracket	MA1026	
Adaptor plate	M1900612	
Robot bracket	M1899539	
Air tube, T tube and Harting conduit	F4091-C (1M) M501902 (2M), P73726 CONDUIT PHANTOM (2M)	



ORIENTATION	
MOTOR	0°
FEEDER	180°
ADAPTO	0°



3MM Tool

Notes

Direct mounted magazine fed robot tool

Appendix D

Source Experimental Data

OBJECTIVE 2

To measure the potential improvement in lead time in the stage one modelling design process by the use of alternative CAD technologies. Lead time is directly linked to design output. Current output is 10 tools/week. New target is 20/week.

	TOOL No.	CONRTOL VARIABLE (Mins) (Traditionl Methods)		INDEPENDENT VARIABLE (New Methods)		DEPENDENT VARIABLE (Mins) (New Methods)	Improvement %	Tool Type
N/A	JL0042-01	150	DPM	Pilot Study	DPM	80	47	Robot
1	JL2001	140	W 1st	Experiment 6	Y 2nd	45	68	Pedestal
2	JL2002	136	W 2nd	Experiment 8	Z 1st	71	48	Robot
3	JL2003	160	W 3rd	Experiment 9	Z 2nd	62	61	Robot
4	JL2004	110	W 4th	Experiment 5	Y 1st	105	5	Pedestal
5	JL2005	120	W 5th	Experiment 10	Z 3rd	46	62	Robot
6	JL2006	82	W 6th	Experiment 1	X 1st	75	9	Pedestal
7	JL2007	108	W 7th	Experiment 3	X 3rd	63	42	Robot
8	JL2008	78	W 8th	Experiment 2	X 2nd	55	29	Pedestal
9	JL2009	77	W 9th	Experiment 4	X 4th	55	29	Robot
10	JL2010	75	W 10th	Experiment 7	Y 3rd	51	32	Pedestal
	Average	109		Average		63	38	Ave Improve

27	Ave Improve	X
35	Ave Improve	Y
57	Ave Improve	Z

Appendix E

Source Experimental Data

OBJECTIVE 3

To measure the potential improvement in lead time in the stage two drafting design process by the use of alternative CAD technologies. Lead time is directly linked to design output. Current output is 8 tools/week. New target is 16/week.

	TOOL No.	CONRTOL VARIABLE (Mins) (Traditionl Methods)		INDEPENDENT VARIABLE (New Methods)		DEPENDENT VARIABLE (Mins) (New Methods)	Improvement %	Tool Type
N/A	JL0042-01	638	DPM	Pilot Study	DPM	166	74	Robot
1	JL2001	525	Z 4th	Experiment 5	Y 1st	449	14	Pedestal
2	JL2002	585	Z 2nd	Experiment 8	Y 4th	459	22	Robot
3	JL2003	655	Z 1st	Experiment 10	Z 1st	466	29	Robot
4	JL2004	495	Z 5th	Experiment 6	Y 2nd	432	13	Pedestal
5	JL2005	570	Z 3rd	Experiment 9	Y 5th	427	25	Robot
6	JL2006	570	Z 6th	Experiment 3	X 3rd	397	30	Pedestal
7	JL2007	537	W 1st	Experiment 2	X 2nd	425	21	Robot
8	JL2008	525	Z 7th	Experiment 4	X 4th	362	31	Pedestal
9	JL2009	530	W 2nd	Experiment 1	X 1st	451	15	Robot
10	JL2010	456	W 3rd	Experiment 7	Y 3rd	412	10	Pedestal
	Average	545		Average		428	21	Ave Improve

24	Ave Improve	X
17	Ave Improve	Y
29	Ave Improve	Z